A Planning Approach for Developing Inventory and Monitoring Programs In National Parks

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Cover Photo: Long-term measurements of Blue Glacier, Olympic National Park, assist scientists in determining the relationship between climate and glacier dynamics.

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Contents

Figures

Tables

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Foreword

In September 1992, the National Park Service (NPS), Office of the Associate Director, Natural Resources, issued NPS-75, the *Natural Resources Inventory and Monitoring Guideline.* This document provides servicewide policy, guidance, and direction to all parks that are designing and implementing comprehensive natural resource inventory and monitoring (I&M) programs. NPS-75 represents the official NPS policy, and I&M efforts at all NPS organizational levels should be consistent with the guidance provided in that document.

NPS-75 is largely conceptual in nature. The guideline is not, and was not designed to be, a “how to” manual. The Inventory and Monitoring Program National Advisory Committee, which guided NPS-75 development, determined that technical protocols on how to implement specific steps of the I&M process be developed independently over time and provided in the form of supplements to NPS-75. The park prototype monitoring component of the servicewide I&M program represents one major effort to develop those protocols in a scientifically valid and expeditious manner.

In this document, David L. Peterson, David G. Silsbee, and Daniel L. Schmoldt offer some conceptual ideas on how individual parks could plan and implement an I&M program. In several respects, their ideas parallel and complement the I&M project planning and development process outlined in NPS-75; however, no universal techniques exist for I&M efforts related to ecosystem management. Many different ideas and approaches need to be tested. The ideas in this document describe a research approach that the Pacific Northwest Region is field testing for implementing the guidance that is provided in NPS-75. As the servicewide I&M Program progresses over time, additional approaches will also be field tested elsewhere in the National Park Service.

Gary Williams
Program Coordinator
Washington Office

Inventory and Monitoring Concepts

The National Park Service will assemble baseline inventory data describing the natural resources under its stewardship and will monitor those resources . . . to detect or predict changes. The resulting information will be analyzed to detect changes that may require intervention and to provide reference points for comparison with other, more altered environments *(Management Policies,* Chapter 4:4, U.S. Department of the Interior, National Park Service 1988).

Resource managers for the National Park Service and other agencies manage an assortment of natural resources, including measurable commodities, aesthetic values, and ecosystem processes (Hinds 1984, Fox et al. 1987, Silsbee and Peterson 1991, 1993). The mission of the National Park Service is to protect and preserve national park system lands, and in order to carry out this mandate, NPS managers need to know what resources they are protecting and when the resources are threatened.

Inventorying provides information on the existence, location, and current condition of park resources. An inventory listing includes species lists, soil maps, and records of past fires.

Monitoring provides an ongoing assessment that tracks the condition of the resources and identifies the threats to their integrity. Monitoring activities include collecting weather data, assessing pH levels in streams, and quantifying the size of elk populations. Monitoring provides managers with information on the possible changes in the condition of the resources.

Greater awareness of the threats to park resources has increased recognition among managers that broad-scale resource I&M programs are needed (U.S. Department of the Interior, National Park Service 1992). With parks throughout the country developing or expanding I&M programs, efforts in defining the scope and methodology need not be duplicated, and some consistency among parks can be developed.

Many parks have implemented I&M programs, at different levels of detail, and with various conceptual approaches (Peine et al. 1985, Davis 1989, Smith and Torbert 1990, MacDonald et al. 1991). For example, the I&M program at Channel Islands National Park emphasizes animal populations (Davis 1989), whereas the I&M program at Great Smoky Mountains National Park includes a range of projects on vegetation, air quality, water quality, and other topics (Peine et al. 1985).

Few parks have established guidelines for developing an I&M program. The *Natural Resources Inventory and Monitoring Guideline* (NPS-75; U.S. Department of the Interior, National Park Service 1992) provides a conceptual approach and organizational framework (Figure 1), but the guideline does not, and was not intended to, address planning, prioritization, and other aspects of I&M programs. General concepts relating to designing and implementing I&M programs are outlined in Silsbee and Peterson (1991, 1993), Peterson et al. (1994), and Schmoldt et al. (1994).

The National Park Service, Wildlife and Vegetation Division, in 1990-91 compiled five standard databases (biological inventory status, vascular flora, vertebrate fauna, thematic maps, and imagery) for 150 national parks nationwide. This effort shows the agency's commitment to the I&M concept.

This report describes a planning approach to assist NPS managers in developing a dynamic, technically rigorous I&M program within any park or in modifying an existing one. The approach is general enough to encompass any type of objective. This procedure assists managers in making decisions for complex situations with numerous alternatives, provides insight into the rationale for the decisions, improves quantifying those decisions, and aids in optimizing the I&M program. The planning approach is flexible enough to be easily modified and updated.

Based on state-of-the-art methods and analyses, this approach provides a consistent framework for many aspects of I&M program development.

Framework for I&M program development:

1. *Establish interdisciplinary approach*
2. *Develop individual I&M projects*
3. *Use planning and decision support tool*
4. *Prioritize I&M projects*
5. *Allocate resources to I&M projects*
6. *Provide quality assurance and data management considerations*

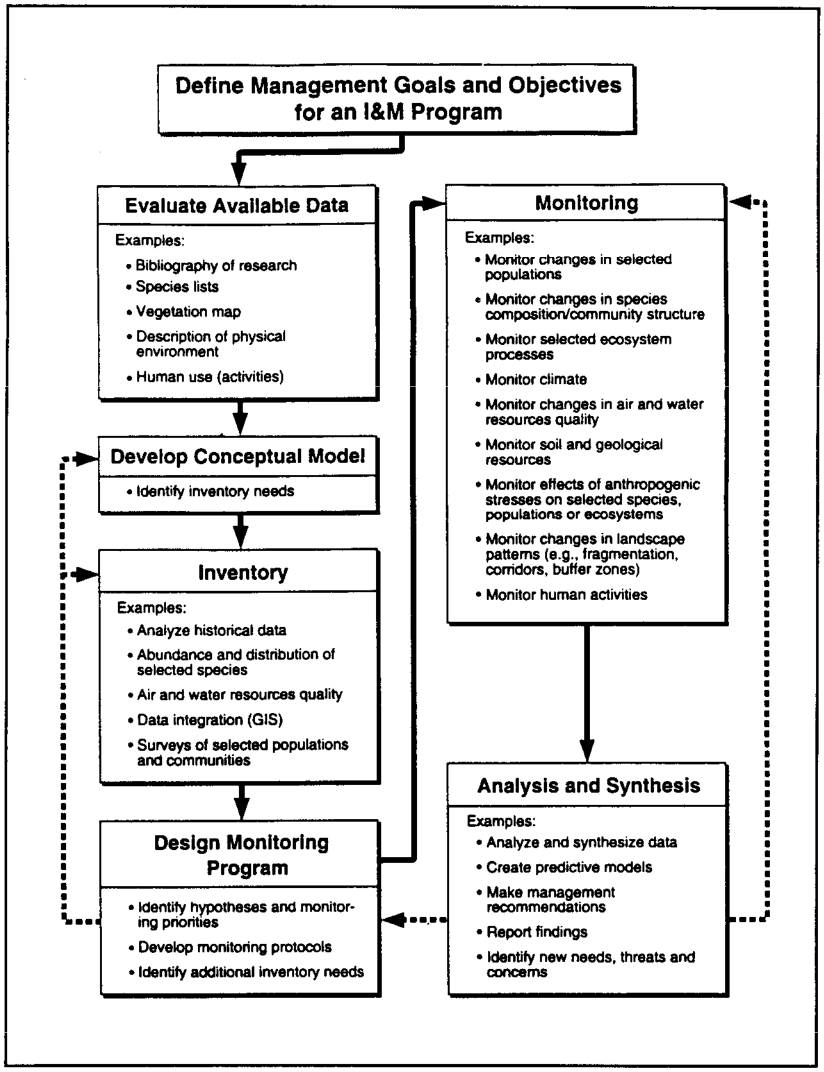


FIGURE 1. Conceptual overview of I&M process. *Source: Natural Resources Inventory and Monitoring Guideline* (NPS-75, U.S. Department of the Interior, National Park Service 1992).

The design encourages interaction between different parks and institutions and addresses a range of scientific and managerial concerns.

The most time-consuming part of the planning approach is writing an I&M plan--an "ideal" document that describes all the projects that a park would like to conduct in order to have a comprehensive I&M program. However, not all of these projects will be implemented because of budget and personnel constraints. An I&M plan is analogous to a park resource management plan that encompasses a range of programs, of which only a subset is implemented. An I&M plan is modified as needed over time. Giving individual projects priorities and allocating resources are conducted on an annual or more frequent basis.

Developing an I&M plan is best accomplished by an interdisciplinary team of scientists and resource managers. This team develops program objectives and a list of individual projects. Individual I&M project descriptions are then needed; these descriptions require considerable background information and reference materials. Because most parks can have more projects than can be realistically implemented, a planning and decision support tool is presented in this report to assist with evaluating and selecting various projects for inventorying and monitoring. This support tool relies on a interactive computer software--the Analytic Hierarchy Process (AHP)--whose use and conceptual background are described in some detail. An example of a park I&M program that uses this software to give I&M projects priorities through a quantitative rating system is provided. The example shows how resources are allocated to I&M projects by including information on budget and personnel requirements as part of evaluating and selecting projects. Finally, an overview of quality assurance and data management considerations, which are an integral part of any program that collects scientific data, is also provided.

Interdisciplinary Approach to Program Development

Proposed I&M programs normally include numerous issues and resources. Few national parks, particularly smaller parks, have the expertise or time to devote to a thorough review of the management and scientific aspects of I&M projects. Identifying all of the projects that are critical or that can potentially contribute to an I&M program is difficult without a wide range of expertise and viewpoints.

An interdisciplinary I&M planning team is developed at the regional level and includes individuals with a variety of professional expertise in resource management and science. The team includes regional office personnel, resource managers from field units, scientists from cooperative park studies units, and individuals from other agencies or institutions.

No prescribed formula is available for forming an I&M team, but the team includes representatives from all of the disciplines that can assist a particular park. Individuals on the team should be committed to participating in this effort for a park and to the broader I&M goals of the region and the National Park Service. Supervisors allocate time in the participant's annual workplan and performance standards.

The I&M team should have individuals who are willing to serve at least 2 years. Approximately 10 people on a team is an appropriate number. Team members change over time, but no more than 3 should be replaced at a time in order to provide continuity. The team includes scientists and resource managers with expertise in the following areas: terrestrial biology, aquatic biology, wildlife biology, earth science, social science, and cultural resources. One or more team members also have expertise in quality assurance procedures and data management. Subject-matter experts are brought in as necessary to serve on the team in a temporary capacity. The I&M coordinator for the region is normally the team leader.

The park resource management staff contacts the team leader when the park anticipates developing an I&M plan or rewriting a plan (Table 1). Park staff provides the I&M team with sufficient background materials to become familiar with the park resources, the available information, and the current resource management issues. The park staff convenes a workshop that includes the I&M team and selected members of the resource management staff. The workshop takes place on-site at the park if possible.

The workshop structure varies, depending on the park and the scope of the proposed I&M program. During the first two days of the workshop, park staff conducts an overview of the park resources, scientific issues, and managerial concerns. The overview includes a considerable amount of time in the field with park personnel. No substitute exists for seeing field sites in conjunction with the discussions with park personnel.

The I&M team directs the workshop after the overview is completed. The team leader conducts an initial brainstorming session, in which all ideas relevant to I&M concerns and potential projects are recorded, with minimal discussion and without negative comments. The team leader then directs any feedback toward clarifying issues rather than debating issues. A team member records all the important points on flip charts, and a designated recorder enters detailed notes into an electronic format.

The team then considers the issues and the projects and organizes them into appropriate subject areas. The next step is to develop a list of potential projects that can contribute to a park's I&M program.

The entire I&M team does this for a small park with a limited number of projects. For a large park, breaking into subgroups is more appropriate to address sets of projects with a common theme. If subgroups are used, participants are encouraged to "float" between groups, as necessary, to provide the appropriate mix of expertise for each issue.

A final list of projects represents a consensus of each subgroup and ultimately the entire group. An extensive list is generally developed that represents an ideal I&M plan, without considering budget or personnel constraints for actually implementing the plan.

The team considers projects that overlap park boundaries or require cooperation with other agencies. The I&M team and park staff reach a consensus on the final list of projects. Proposed projects are generally retained on the list if members have any doubts about including them.

TABLE 1. Summarv of interdiscinlinarv process to develop an I&M plan.

1. Initiation of Process - park resource management staff

    Contact I&M team leader
    Provide background materials to I&M team

2. Workshop - I&M team and selected members of park resource management staff (preferably on-site at park)

    Conduct overview in conjunction with field site visits
    Initiate brainstorming session
    Conduct project listing process
    - organize issues and projects into subject areas
    - list potential I&M projects
    - develop final list of I&M projects (by consensus)
    Write detailed description of each I&M project

3. Draft I&M Plan - I&M team leader in cooperation with park resource management staff

    Collate I&M project descriptions
    Write overview statement (conceptual design and rationale)
    Include the following in draft I&M plan:
    - overview statement
    - project descriptions
    - table of projects (estimated budget and personnel requirements)
    - reference materials

4. Review - I&M team, park staff, other NPS staff (regional chief of resource management, etc.), and other interested parties (adjacent landowners, etc.)

    Circulate draft I&M plan for review

5. Final I&M Plan - I&M Team Leader and Park Resource Management Staff

    Prepare final I&M plan, following consideration of review comments

The next task of the group is to develop a detailed description of each I&M project. The team leader assigns writing tasks to individuals with the greatest level of competence and interest in a particular project. Each proposed I&M project is given a name and geographic location (Table 2). Project names and locations are general or specific and refer to projects that cover small areas, the entire park, or parklands plus adjacent lands. Many projects are multidisciplinary, and multiresource categories from Appendix A are used as necessary. For example, a project that monitors amphibians is relevant to both terrestrial and aquatic systems. The ecosystem-landscape type is also indicated in some nomenclature designated for each region. The annual cost of each project and the required number and type of personnel are indicated.

Project descriptions discuss scope, objectives, and methodology. The group prepares the descriptions in a standard, concise format (Table 2). These descriptions are prepared at the workshop if sufficient time is available; computers expedite this task. At the least, the team prepares the outlines for each project during the workshop.

An additional topic that the team considers at an I&M workshop is prioritizing the I&M projects, The team conducts this process using a planning and decision support tool, such as the AHP software. The I&M team leader explains to the group how this process is used to prioritize projects and optimize resource allocation; a brief demonstration of the software quickly illustrates the fundamentals of this

TABLE 2. Sample format for summarizing an I&M project.

Inventory and Monitoring Plan	Olympic National Park
Resource Management Plan Reference No:	N-608.108S
Project Title:	Status of Anadromous Fish Populations
Location:	All major streams on north and west side of park
Classification:	Fauna/vertebrates/aquatic/fish/distribution and abundance
Ecosystem-Landscape Type:	Riparian/Douglas fir-western hemlock
Annual Cost:	$41,000
Annual Personnel Requirement:	1.75 FTE
Project Description:	

process. Drawing on the expertise at the workshop is helpful in rating projects with respect to various criteria, and in deciding which projects can actually be conducted.

The group rates the projects in a straightforward manner, quickly and efficient y. The group considers these ratings as input for park resource management staff, who have the final word on the ratings. (See the Planning and Decision Support Tool for Inventory and Monitoring section in this report and Schmoldt et al. (1994) for more details on this topic.)

The team leader collates the I&M project descriptions into a draft document by a date agreed on at the workshop. The team leader, in cooperation with park staff, prepares an overview statement that discusses the conceptual design and the rationale for the I&M program.

The team leader and park staff then circulate the draft I&M plan for review among the I&M team, park staff, the regional chief of resource management, the regional chief scientist, and other NPS staff, as appropriate. Obtaining reviews from other agencies and institutions is advisable, particularly from parties with interests in natural resource management issues in the park (e.g., agencies with adjacent landownership, such as the U.S. Department of Agriculture, Forest Service). The team leader and park staff prepare the final I&M plan after considering the review comments.

A final I&M plan contains:

1. *Overview statement*
2. *Project descriptions*
3. *Table of projects with estimated budget and personnel requirements*
4. *Reference materials and other relevant information*

Developing Inventory and Monitoring Projects

The list of projects that an interdisciplinary I&M team develops includes projects that contribute to the knowledge of park resource conditions. The list includes enough detail to allow the team to make informed judgments about the various criteria that are involved in prioritizing the projects. The uses of the data, how well the data will meet park objectives, and how the data will fill in the gaps of existing knowledge should be clearly understood. Furthermore, a reasonably accurate estimate of cost in both dollars and personnel is made before selecting and prioritizing the projects.

A detailed project description requires that background information and reference materials provide the conceptual and technical basis for project implementation. To aid in these descriptions, an overview of the I&M projects and methods is provided for each resource category and level of effort (see Appendix A). The resource categories in Appendix A are generic enough to fit any program. Although the information is not comprehensive, additional categories are added as needed. The I&M team can also use a classification such as the one in the NPS Pacific Northwest Region natural resource database (Wright 1993). No single list of appropriate projects or I&M methods are appropriate for all parks because of the differences among national parks in the types and extent of resources, number and expertise of personnel, funding, and extent of existing data. This report does not attempt to develop such a list or to define the "correct" method for any type of project. Rather, this report makes some general suggestions for each category concerning high-priority projects, lists sources for detailed information on methods, and cites examples of completed projects. This report is not a comprehensive summary.

I&M activities for each resource category are classified according to the level or intensity of effort that is required to obtain the information. We suggest a simple conceptual approach to planning I&M activities.

> *Conceptual approach to I&M planning:*
>
> *1. Compile existing information*
> *2. Conduct resource inventories*
> *3. Establish monitoring*

The team indicates the level of effort for each I&M project, including the current and the planned effort. For example, a park that plans to determine the effects of air pollution on plant species may already have some data on sensitive species (#1 (current)) compile existing information), but would like to determine if other sensitive species are present (#2 (planned) conduct resource inventories) and evaluate visible symptoms for several years (#3 (planned) establish monitoring). The team does #1 before #2 and #3, and #2 before #3, but makes exceptions as necessary. (These three levels are not intended to correspond with phases I, II, and III in the *Natural Resources Inventory and Monitoring Guideline.)*

The following general discussion focuses on the kinds of information and activities that are anticipated at each level of effort.

Compile Existing Information

Existing information includes virtually any source of quantitative or qualitative data, such as historic information, data in published and unpublished documents, and personal knowledge. Event records with dates and descriptions of important phenomena (such as fires, windstorms, floods) are of particular value. Identifying the quality of the information that is collected and providing an estimate of the confidence in its accuracy are important.

Compiling existing information does not actually involve any resource inventorying or monitoring. Nevertheless, compiling what information exists prevents wasting time and money collecting information that is already available. Also, compiling existing information provides a better understanding of the data gaps in an I&M project.

The following two types of existing information are compiled:

1. *Actual data from the park and surrounding area.* Data from past surveys, research projects, or existing monitoring activities are found in a variety of sources. Existing data make new projects unnecessary, allow new projects to stretch resources further, or simply provide background information to assist in developing an I&M project.

2. *Published or unpublished reports, observations, and analyses of existing data.* Actual data sets are often not available, but reports and summaries of the data are. Lack of quality assurance, inconsistency with modern methods, or other data-quality problems make direct use of older data sets for monitoring difficult. Nevertheless, the conclusions and analyses based on the data at the time may still be valid. In other cases, studies in adjacent areas or similar areas offer insights into park resources, although the actual data were not collected in the park. Finally, historic observations of significant events, settlement patterns, disturbance patterns, and other factors that are important to interpreting current trends are often available only in anecdotal form. This type of qualitative information about park resources cannot necessarily be directly translated into numerical data. However, the information is relevant to the design of an I&M project and how the new results are interpreted.

For actual data sets, reference is made to the types of data available, dates of data collection, sources of the data, personal contacts, and as much information as necessary to provide a basic description of the data set (e. g., Peine et al. 1985). An annotated bibliography is more appropriate for published reports and other qualitative information. Bibliographic citations are sufficient to allow someone to find even unpublished documents, and annotations convey the type of information contained in the reference. For example, bibliographies of information relevant to Great Smoky Mountains National Park have been published for a variety of resource categories (e.g., DeYoung et al. 1982, DePriest 1984, White 1987), and small grants funded the periodic data collection.

This information is ideally compiled into a computer database that is searched by subject matter and geographic area (e.g., Parker et al. 1989), but a printed bibliography is a useful first step. Many projects with a high priority for funding early in an I&M program consist of compiling the existing information on a particular subject rather than collecting new data.

Conduct Resource Inventories

Resource inventories include information on the existence or condition of the various resources. One of the best examples of this information is a species list for some particular taxon, such as vascular plants. Beyond simply naming the species, an inventory database includes details on abundance, distribution, special status (e. g., endangered species), etc. Some indication of the condition of a resource is also included, such as the current pH of a lake or the heavy metal content of the soil. These details are essentially one-time measurements. Some short-term research projects fall under this level of effort. Many inventory projects involve mapping resources, such as vegetation, soils, or geology. Computer geographic information systems (GIS) are ideally suited for storing, manipulating, and displaying many types of inventory data.

In general, an inventory project involves a greater intensity of sampling or more extensive sampling than a monitoring project, because an inventory project does not have to maintain that level of effort year after year. As a result, inventories are good for determining patterns over large geographic areas (extensive sampling) and measuring large numbers of parameters (intensive sampling). Because inventory projects do not involve a long-term commitment to continued sampling, they are an appropriate way to use onetime funding.

Resource inventories are used as starting points from which monitoring programs are developed. A geographic survey of any type of resource provides a basis for selecting representative monitoring sites. This type of survey also determines the variability that is expected among monitoring sites and, therefore, helps in determining the sampling intensity-location combinations that are needed for a monitoring program. Other types of inventories, such as species checklists, identify the need for particular types of monitoring, such as monitoring of rare plant populations. A short-term inventory involving a large number of parameters or many species also determines which parameters or species are included in a monitoring program.

Resource inventories are also used to extrapolate monitoring results. For example, a short-term collection of weather data from several sites is used to develop regressions between those sites and a single site with a long-term monitoring record. Those regression results are then used to estimate longer-term conditions for all the sites.

Establish Monitoring

Monitoring refers to repeated measurements over time that permit changes to be assessed in a particular resource. This level of effort is generally time-consuming and expensive. Fewer parameters and fewer sites are included in a monitoring program than in a onetime inventory. Only a few of the many possible monitoring parameters are included, and they are done as efficiently as possible. Careful planning is required to collect accurate data using appropriate methods, monitoring design, quality assurance, and analysis. Monitoring data need to withstand scientific critiques and to stand up in a court of law. Details of the monitoring activities are recorded and archived. Long-term data storage and handling are essential.

Monitoring is the heart of a program aimed at tracking resource conditions and evaluating the threats to resources. No matter how much is known from a onetime inventory, monitoring over time is needed to evaluate trends. A short-term study identifies a threat and its impact, but monitoring data showing a change in resource condition over time provide a clearer demonstration of the impacts.

The amount of "essential" information to be collected with limited funding is frustrating for resource managers, but relatively inexpensive steps can be used to initiate a program. Managers can establish a systematic record of events, such as major tree blowdowns, fires, landslides, unusual weather, etc. Although the ideal event record is computerized, indexed, and linked to a GIS, data stored as hard copy in a file cabinet is better than nothing. Useful low-cost monitoring is also done with repeat photography.

Photographs that carefully document the location, date, and time are used to monitor a diversity of resources, such as vegetation, air quality, campsite condition, and glacier activity.

Conducting monitoring programs over long periods of time also raises more serious quality assurance considerations than short-term studies. Changes in personnel, attitudes, and techniques are considered to ensure that data gathered today can be compared with those collected in the future.

Develop Projects for Individual Resource Categories

Atmospheric

Compile Existing Information. Weather and air quality information exist in or near parks in many cases. If the park itself does not have a weather station, a station can be located nearby. Similarly, if no air quality information exists for the park, data are found at a state agency or other source somewhere in the vicinity. Park staff should consider how representative the weather and air quality information is for the park as a whole, regardless of whether or not the information is obtained from a site within park boundaries.

The first two places to look for weather information are the commercial weather databases and the National Weather Service database at the National Climate Data Center in Asheville, North Carolina. National Weather Service data are increasingly available from commercial sources in CD-ROM databases. These data are easily accessed, contain detailed information from a large number of sites, and are available free of charge at many libraries. The National Climate Data Center contains a huge database, including data from more obscure sites, short-term records, and older records not in electronic format. Some data are available only in paper form for a fee. Other sources of information include fire weather records, to which park fire management personnel have access, and park headquarters or ranger station records not sent to the National Weather Service.

The first contact in the National Park Service for compiling existing information on air quality is the Air Quality Division. The Air Quality Division is familiar with most air quality monitoring activities in and around national park system areas, knows the state agencies involved, and can direct parks to various data sources. The Air Quality Division can also assist with weather records because the division uses weather data in processing air quality data; most air quality monitoring stations also collect weather data.

The National Atmospheric Deposition Program/National Trends Network (1989) is the best source for wet deposition data. Other data are located from specific research projects. The National Atmospheric Deposition Program has a network of some 200 sites around the country, including many national parks.

The most important element in the early stages of compiling existing information is to produce a complete, accurate list of what is available and who has it, not to actually acquire the data. Weather and air quality monitoring produce large quantities of data that are continually updated. Acquiring the data when they are needed so that they are up-to-date and complete is generally preferable. Trying to obtain portions of the data intermittently duplicates the efforts of data managers for individual programs.

Conduct Resource Inventories. Inventory activities for weather and air quality information take the form of short-term data collection or research projects. The goal is often to see how well a small number of sites within (or outside) a park represent the park as a whole. The Air Quality Division also monitors air pollutants on a short-term basis to determine if a sufficient problem exists to warrant long-term monitoring.

Inventories of weather and air quality include (1) comparing temporary monitoring sites with a site having a long-term record, (2) studying micrometeorologic variability, and (3) sampling air quality or atmospheric deposition on a short-term basis. The methods are generally the same for long-term monitoring, but the focus is on identifying spatial patterns rather than monitoring long-term trends. This type of inventory is useful in determining the most appropriate sites for subsequent long-term programs, but this method is also expensive.

Establish Monitoring. The best source of information for establishing atmospheric monitoring programs is the Air Quality Division. The division has a nationwide network of air quality and weather monitoring sites and is familiar with protocols, instrumentation, and problems associated with this type of monitoring. The National Weather Service is another source of information on weather monitoring. (See Halvorson and Doyle (1988) for an example of a weather monitoring program.)

Geologic

Compile Existing Information. Existing geologic information is likely found in U.S. Geological Survey (USGS) publications or academic literature. Every national park should have, at the least, USGS topographic maps and a bedrock geology map that describe rock types (e.g., Tabor and Cady 1978). If not available specifically for the park, a geologic map for a larger area including the park is certainly available.

Soils information is not available for many national parks, but at least some general descriptions are found on parent materials, surficial geology, or landform units. The U.S. Soil Conservation Service has information on soils throughout the United States, although only general descriptions and classifications for nonagricultural areas are usually available.

Records of sediment movement and geothermal activity are not likely found except in special circumstances. If these phenomena are important in a particular area, inquiries through appropriate agencies or a search through the academic literature can locate existing data. An event record is an important component of a monitoring program for geology. Most information for this record exists in park files but is difficult to access. Records of major events, such as landslides, volcanic activity, fires, floods, historic human disturbance, and any other events likely to be significant in interpreting current resource trends, are filed and organized so that they can be searched by topic, location, and chronologic sequence.

Conduct Resource Inventories. Resource inventories for geologic resources are undertaken mainly to fill in identified gaps in the existing information. In general, these inventories are intensive field surveys that professionals conduct in a particular area of interest (e.g., Popenoe 1990).

Establish Monitoring. Most geologic processes are sufficiently slow that monitoring is not a realistic endeavor. Records of catastrophic events are kept and the event record maintained through time. A few geologic processes warrant attention in particular cases (e.g., sediment transport along coastal barrier islands, geothermal activity). Some soil properties also warrant monitoring. Special methods are developed for the particular cases in which monitoring is to be conducted. The U.S. Geological Survey, the U.S. Soil Conservation Service, and academic scientists are the best sources of assistance. Soil erosion and stream sediment transport are the only categories for which generally accepted monitoring techniques exist (e.g., Kirby and Morgan 1980, Reynolds et al. 1990).

Hydrologic

Compile Existing Information. Because of the importance of water for all facets of human existence, data on quantity, distribution, and physical and chemical characteristics of all forms of water are available. Before attempting any inventory or monitoring activity for these resources, conduct a thorough search for existing data sources. Many possible sources contain information. The NPS Water Resources Division can assist with water resource issues in national parks and with identifying existing information.

The U.S. Geological Survey and other agencies operate stream and river gauging stations throughout the United States. Most stations have continuous discharge records over extended periods of time, and many have associated physical and chemical measurements. Some stations are officially designated as trend stations, performing more measurements and paying more attention to the consistency of the records than other stations. Data from some of these sites are available directly from either the U.S. Geological Survey, the Water Resources Division, or on CD-ROM at university libraries.

State, local, and regional water and fisheries agencies, municipal water treatment and sewage treatment plants, agencies operating hydroelectric plants, and flood-warning systems often operate similar stations. The type of measurements, degree of quality control, and duration and continuity of the records vary greatly. Watertable depth is also monitored where groundwater is used for a water supply. Snowpack is monitored in mountainous regions to predict runoff for water supply. These data sources are found primarily for accessible portions of larger streams and rivers. The best recent information on lake characteristics in the western United States is in the Western Lake Survey (Landers et al. 1987), which includes many lakes in national parks. Additional data found for individual parks should be used with caution because of the temporal variability in many aquatic systems.

One of the best sources for existing water quality data is the Environmental Protection Agency (EPA) STORET water quality database. The STORET database stores water quality data from the Environmental Protection Agency, the U.S. Geological Survey, and many state and federal agencies. The Water Resources Division recently initiated a program to download water quality data for national parks from the STORET database. The data are being downloaded to individual park personal computer databases, and several basic analyses are being performed. The Water Resources Division should be contacted for assistance in acquiring water quality data from the STORET database.

Individual parks also conduct some water quality monitoring and can be contacted regarding water quality data at parks.

Conduct Resource Inventories. The most basic inventory of water resources is a list of what exists; sources, general sizes (for lakes or streams), and water uses add to the usefulness of the information. This information is ideally on a GIS, but even in list form the data provide a basis for further work.

A broad survey of physical and chemical characteristics (including water volume) is the next step in a water resource inventory (e. g., Silsbee and Larson 1980, Landers et al. 1987). A subsample of lakes and streams is necessary in most areas, with samples taken from a variety of different water sources. Methods for this survey depend on the amounts and types of water resources present. The Water Resources Division can assist with designing and developing water resource inventories.

Establish Monitoring. Hydrologic monitoring includes measuring water volume, chemical characteristics (such as acidity and nutrient concentrations), physical characteristics (such as temperature and suspended sediment), and biological parameters (such as enteric bacteria or benthic invertebrates). Although many of these parameters are not strictly hydrologic, they are mentioned in this section either as indicators of hydrologic conditions or because the concern is with the aquatic system as a whole rather than just the water.

In general, monitoring streams and rivers involves setting up a continuous recording of stage height as an indicator of water volume and measuring other parameters periodically at the same or associated sites (e.g., Voshell and Hiner 1990). Careful attention to the timing of sampling is essential because of temporal variation in aquatic systems (year-to-year variation, seasonal variation, and response to short-term storm runoff events).

Lakes have a different set of measurement problems. Significant differences are found in many parameters with location and depth because lakes tend to mix much more slowly. The timing of such events as spring ice melt, thermal turnover, and winter freezing is also important. Adequately characterizing the condition of a lake is expensive because of the complexity of measurements and interactions. A direct tradeoff exists between how well a lake is characterized and how many lakes are sampled.

Snowpack monitoring is frequently conducted in conjunction with predicting water supply from spring runoff. Monitoring is generally measured once; the goal is to sample at the peak time before snowmelt begins. The duration of snowpack is potentially important ecologically and is sensitive to changes in climate, but is less frequently monitored.

Geothermal and glacier activity monitoring is needed in locations where they are important resources. Geothermal activity monitoring is specific to a particular location, because geothermal features vary widely. The extent of glaciers is effectively monitored using repeat photography or aerial photography if it is done at the appropriate time of year. Measurements of mass balance require more complex techniques and are done with a glaciologist.

The Water Resources Division should be consulted in designing monitoring programs for water resources (e.g., Flora and Kunkle 1986). The Environmental Protection Agency has published guidelines and a computer expert system to assist in designing monitoring programs for streams potentially affected by forestry activities (MacDonald et al. 1991). The EPA publication describes a number of monitoring parameters and guidance in setting up a program.

Flora

Compile Existing Information. Information on flora includes academic research, vegetation maps, flora checklists, regional manuals, and herbarium records. Most of this information is located through an academic literature search. Discussions with local botanists can reveal the existence of local checklists, herbaria, etc. Existing information is best "compiled in an annotated bibliography, with only the most important sources actually being acquired. The information is evaluated closely before further inventory or monitoring.

Conduct Resource Inventories. The two most important inventory projects are (1) an up-to-date, complete, reliable annotated checklist (e.g., White 1982) and (2) a vegetation-type map and associated descriptive information (e.g., Agee et al. 1985, Agee and Kertis 1987). The checklist ideally includes information on the distribution and the habitat requirements of species, abundance (rare, common), distribution (especially if endemic or distribution is restricted), legal status (endangered, threatened, or other classification on national or state lists), and origin (if alien, or nonnative). Some of this information is available in NPS databases, including the NPFLORA database. These databases are incomplete for many parks. Even parks with well-researched checklists should look for new species. Alien species, in particular, are likely to be recently introduced or overlooked in checklists.

Most checklists include only vascular plant species, but I&M planners ideally compile lists for other taxa as well (e.g., Smith 1990).

Vegetation maps are generally produced from a combination of either satellite data or aerial photography and field plots. The field plots are sampled to characterize the vegetation and to verify the identifications that are made from various types of imagery. Satellite data or photography is used for mapping the geographic location of vegetation types. Aerial photography is generally more accurate but time-consuming for large areas and is not effective for identifying changes if the project is repeated in the future. In any case, the information is not immediately in the digital form that a GIS requires. Satellite data, on the other hand, provide a product that is available immediately in a computer format which is suitable for further use in a GIS, with algorithms for translating reflectivity values to vegetation types that can potentially be applied to future data for evaluating changes. However, some loss of both resolution and accuracy does occur, compared with aerial photo interpretations, and the mechanics of georeferencing and interpreting the data for small areas are likely more time-consuming than direct interpretation of aerial photos. Digital orthophotos are valuable for mapping vegetation in relatively small areas because the data are already digital and georeferenced, are high resolution, and use manual and computer-assisted classification techniques.

Establish Monitoring. Vegetation monitoring determines the trends in community structure and composition for specific purposes, such as for tracking rare or alien species, or for evaluating human impacts such as trampling. Monitoring is usually best conducted using a system of permanently marked sample plots that are resampled on a regular basis (e.g., Davis 1988, Halvorson et al. 1988, Smith and Torbert 1990). The type and location of plots, sampling methods, and frequency of sampling depend on the type of vegetation and purpose of the monitoring. Some useful information on subjects such as converting vegetation types on a large-scale (e.g., meadow to forest) or tree mortality is gained through repeat photography, a relatively inexpensive and easily implemented form of monitoring (e.g., Gruell 1983).

Studies of tree-ring growth increments provide an interesting "retrospective monitoring" capability because the record of tree growth starts many years before monitoring is initiated. Tree-ring data quantify long-term tree growth responses to climate, air pollution, and other environmental factors for which long-term measurements are not available (Peterson et al. 1991). Tree-ring studies are also one of the few methods that provide a long-term record with a one-time effort.

Fauna

Compile Existing Information. As with flora, much information on fauna is available. Regional- or park-specific manuals or checklists, research reports, and wildlife management agency data are the most likely sources of existing information. The best way to start looking is with an academic literature search. As with any subject, discussions with local or regional experts in the field may reveal more information than many hours of independent searching. Compile existing information in an annotated bibliography "at first; acquire only the most important sources. Acquiring more actual data or reports is necessary before further work.

Conduct Resource Inventories. The first level of resource inventory is an annotated species checklist, such as the NPFAUNA database. Although a list of vertebrate species is available or easily assembled, a complete list of invertebrates may never be completed for most parks. Listing invertebrate species is left to specialists for individual taxonomic groups. A more detailed inventory with population estimates or distribution maps is conducted (e.g., Hoffman 1988), if feasible--usually only for species of special interest such as large mammals, disruptive alien species, and rare or endangered species. Inventory techniques are unique to individual species or species groups.

Establish Monitoring. Techniques for monitoring fauna are highly specific to particular species or species groups. In general, parks obtain an estimate or an index of population density or population size annually. Trends are identified only after a long period of monitoring to evaluate natural population fluctuations. For longer living species, determining mortality, recruitment, and age structure of the population make fluctuations in the population density much easier to interpret and predict, but also make monitoring much more expensive. Some examples and discussions of monitoring methods are found in manuals for Channel Islands National Park (Halvorson 1984, DeMaster et al. 1988, Lewis et al. 1988, Fellers et al. 1988, van Riper et al. 1988, Sauer and Droege 1990).

Ecosystem and Landscape Structure and Function

Compile Existing Information. Existing information on ecosystem processes is likely found only in scientific literature. This resource category includes information on similar ecosystems outside the park and data from inside the park. Because ecosystem studies are generally conducted intensively on small sites, they are not necessarily conducted within park boundaries to represent park ecosystems. The goals and techniques of ecosystem-level research projects are highly variable. Compilation is in the form of a bibliography of ecosystem studies relevant to park areas.

Landscape-level work relates more to bringing together geographic information from a variety of resource categories than to collecting new information. A compilation of landscape information involves identifying past work on landscape issues and sources of geographic information that are important to future analysis. Existing aerial photography and satellite data as well as mapped information are identified. Some of this work has been done as part of the NPS Phase I inventory project. The most important approach to compiling landscape-level information is digitizing geographic information about the park and surrounding areas and making it accessible in a GIS. All mapped information and imagery ideally include the park and areas surrounding the park.

Conduct Resource Inventories. Ecosystem-level attributes are difficult to measure and, therefore, do not lend themselves to inventory projects. Ecosystem studies are time- and labor-intensive and are generally done on one or only a few sites. Inventory projects on related subjects such as vegetation types or water chemistry are useful in designing or interpreting ecosystem studies or ecosystem monitoring, but a project that is truly an ecosystem inventory project is not typical.

A landscape inventory includes areas outside the park and the park itself. Inventorying land use around the park and other protected areas in the vicinity is needed to define the park's role in the overall landscape and the degree to which it is an isolated habitat island (e. g., Clark et al. 1991). This inventory is done from aerial photography or satellite imagery. Other resource categories, including disturbance patterns, wildlife movements, and vegetation communities, are also viewed in terms of spatial patterns. Spatial boundaries are delineated to some extent by analyzing mapped information and GIS data rather than by acquiring new data.

Establish Monitoring. Monitoring ecosystem parameters is generally done by intensively studying an instrumented, small watershed (e.g., Edmonds et al. 1991). Because of the intensive work involved and the instrumentation on the site, I&M planners should identify a site that has low visitation and devote it to scientific study.

Landscape monitoring is largely a matter of keeping landscape questions in mind while implementing other monitoring programs (e.g., Knight and Wallace 1989). Scientists have a tendency to think at a landscape scale while in an inventory mode, then focus on a small number of sites for monitoring. The spatial picture tends to be lost as monitoring concentrates on temporal trends. Monitoring a small number of sites is a concession to fiscal and logistic necessity, but the goal is still to know something about the park as a whole. Addressing landscape-scale issues does not necessarily require actually monitoring landscape parameters, but it does require addressing questions of how monitoring sites fit into the overall landscape when monitoring results are analyzed and interpreted. The relationship of the park to the surrounding landscape differentiates this resource category from the others because landscape monitoring includes monitoring the surrounding land use. In general, the best approach to land use monitoring is a periodic inventory.

Nonrecreational Human Activity

Compile Existing Information. Livestock grazing, mining, nonrecreational wood gathering, and historic artifact gathering are permitted in only a few parks. Native Americans and other rural residents participate in subsistence activities in most of the national parks in Alaska. Existing information is generally available only within the National Park Service, either in individual parks or at regional or national offices. Reviewing the permit records gives some idea of the collecting activity. Not much information is available on the extent or effect of gathering berries, fungi, or plants for personal or commercial use.

Air traffic is a significant issue in many national parks. Some data exist on the number and the extent of flights where permits are required, but in most cases, few records are available. Studies have been conducted on the noise levels and the effects on the visitor experiences where noise from air traffic is an issue.

Vehicle traffic is monitored on park roads using vehicle counts. In many cases, scientists have studied the composition of the traffic (passenger cars, trucks, buses, NPS vehicles). However, this information is often out-of-date and inaccurate. Records are found where permits are required for commercial vehicle traffic. Noise and air quality effects from traffic are rarely studied, and existing information is probably not available.

Park activities, such as road maintenance, facility construction, and scientific studies, affect water quality, vegetation, and wildlife. Such impacts are addressed to some extent in environmental assessments for particular projects. However, many activities are not subject to environmental assessment, and their impacts are not evaluated.

Information on historic human use is found in the park archives. Other sources are local historic writings, oral history accounts, and long-time residents of the area. Although much of this material is of a cultural rather than a natural resource nature, this material is relevant to natural resource monitoring because it describes past human disturbance patterns and locations. This information is ideally compiled into a map or GIS form with descriptive material (e.g., Pyle 1985).

Conduct Resource Inventories. Livestock grazing, mining, nonrecreational wood gathering, and historic artifact gathering are permitted only in isolated circumstances. Other federal agencies are appropriate sources of information for these activities, particularly the Forest Service and the Bureau of Land Management. I&M planners can draw inferences from data and studies conducted outside park boundaries to estimate the condition of similar sites inside the park. Scientists interview residents who use park resources to determine the amount of subsistence activities and their effects on resource condition.

Conducting an inventory on gathered and consumed berries, fungi, and plant material is difficult because these activities are normally sporadic and dispersed. One effort to evaluate the effect of visitor collection on two species of orchid (Bratton 1985) used the accessibility of a location as a surrogate for harvest information and examined differences in population structure between accessible and nonaccessible areas. However, this technique is not suitable for all species.

Scientists take simple counts or noise measurements to inventory air traffic activity. Determining what is legal and what is not is more difficult, however. Controversy in Grand Canyon National Park has resulted in a greater focus on air traffic monitoring and policy in national parks.

Vehicle traffic is counted at park entrances using traffic counters. The inventory data most likely to be missing is a breakdown on the types of traffic. Systematic observation of traffic provides information on vehicle occupancy, types of vehicles, states of origin, and types of traffic (commercial, personal, National Park Service). Actual surveys of drivers are necessary for information on the destinations, activities, and demographics of the vehicle occupants.

To inventory the impacts of NPS activities on park resources, scientists evaluate the activities of the various divisions on a case-by-case basis. If this evaluation is done systematically for all park operations, NPS administrators would have an interesting overall view of the impact of park management and an idea of the areas that can be improved.

Information on past human use of an area is supplemented by field investigations to map signs of past use that are still apparent on the landscape.

Establish Monitoring. Information is available from other federal agencies on the methods that are used for determining the impacts of livestock grazing, mining, nonrecreational wood gathering, and historic artifact gathering on resource conditions. An example of a commercial fisheries monitoring program is found in Forcucci and Davis (1988). The National Park Service strongly emphasizes determining patterns and impacts of subsistence activities in Alaskan parks, and techniques for information gathering and monitoring are available from the National Park Service.

Monitoring gathered and consumed berries, fungi, and plant material is becoming more important in some parks where illegal commercial harvest is conducted. If these activities are a high-priority concern, the impacts of these activities are probably best monitored by comparing areas that are heavily collected with those having low visitation. However, finding good controls is difficult.

Monitoring air traffic activity is conducted using methods similar to those discussed under the Conduct Resource Inventories in this subsection. Methods are simplified and standardized to provide year-to-year consistency. Experience in Grand Canyon National Park provides the best guide for future directions in air traffic monitoring.

Monitoring vehicle traffic is probably done using existing traffic counters. Short-term studies that verify reliability and enumerate the types of vehicles provide the essential background for interpreting traffic counts, but need not be continued year after year.

Monitoring the impacts of NPS activities on park resources is an ongoing part of park operations. Although environmental assessments are performed for new projects, I&M planners should also consider reviewing the effects of ongoing operations.

Recreational Human Activity

Compile Existing Information. Data on recreational fishing and hunting (where permitted) are found at state fish and wildlife agencies or in a national park itself. Although data should exist on the number of permits that have been issued, these data may not relate closely to either hunting or fishing activities or to harvest levels in national parks. Direct harvest data exist in many cases, particularly for hunting, although the data's reliability varies and is often not specific to parks. No reliable estimates of illegal hunting or fishing exist. State agencies, the National Park Service, or independent researchers must estimate fish and wildlife populations.

Although the National Park Service is virtually the only source of information on the amount of backcountry use in national parks (Marion et al. 1993), much information is published in the academic literature on the patterns of use and likely impacts. Backcountry permit and trailhead register information are the two most common kinds of backcountry use data. Neither is highly reliable because many visitors fail to sign in and others show up after obtaining a permit. Some areas have used an infrared beam or foot pad counters to measure trail use, but those techniques have reliability problems and are likely available in only a few locations. Many parks and cooperative park studies units have conducted surveys of backcountry users to obtain more detailed and reliable information. NPS surveys are the most likely source of data cm backcountry impacts.

Records of developed area use exist from vehicle counts, visitor center counts, campground occupancy records, and concessioner records. Although most of these records reveal only the number of vehicles, groups, or visitors, campground fee stubs also show state or zip code of origin.

Conduct Resource Inventories. Inventorying human activity is most frequently done through surveys where existing data sources are insufficient. Well-designed and well-conducted surveys of appropriately selected samples of visitors give information on hunting and fishing activity and harvest levels; on the types, duration, and frequency of backcountry and developed area use; and on the attitudes of visitors (e.g., Johnson 1990, Johnson and Lenard 1990). If compared with the visitor counts and the permit data concurrently, a survey also provides an indication of the reliability of these less labor-intensive techniques and a benchmark for adjusting the results.

Surveys do not provide information on illegal activities or on impacts. Some information on illegal activities is obtained from case incident reports, but most illegal activity is presumably never reported. The only type of illegal activity that is reliably inventoried is that which occurs in highly visible locations where someone unobtrusively watches and records the activity. Observers perform reliable inventories on visitor activities that are not in compliance, such as feeding wildlife in developed areas or failing to walk on established trails.

The impacts of human use are generally more easily inventoried than the use itself. Well-developed techniques exist to inventory trail and campsite conditions (Cole 1983a, b; Marion 1991). (See Parsons and MacLeod (1980) and Bratton et al. (1978) for examples of inventory projects on campsite condition. Also see Bratton et al. (1979) for an example of a trail inventory project.)

Establish Monitoring. Monitoring human use is done with techniques similar to those for compiling existing data. Counts of visitors are obtained on a regular basis through a variety of electronic and mechanical counting devices. The quality of the data gathered is estimated as soon as possible. Visitor surveys are repeated over time, but a lag of several years normally occurs between samplings. These samplings are also expensive to conduct, and a fairly large sample size is needed to provide useful information. An example of a visitor monitoring program is described in Davis and Nielsen (1988).

Monitoring the impacts of human use on trails and campsites is done through repeat measurements of the same type used in inventorying (Marion 1991). All campsites are included in a monitoring program rather than a subsample, so that the range of measurements is restricted to reduce sampling time (Cole 1983a). Trail impacts are determined with simple measurements such as width and depth of tread at randomly selected points (Cole 1983 b). The same points are not relocated for resampling over time.

I&M Planning and Decision Support Tool

An interdisciplinary I&M planning process and project development require a considerable amount of time and effort. Most parks will be able to develop a broad I&M ideal plan that encompasses a diversity of projects. However, budgetary and personnel limitations may constrain implementing these projects. Managers should decide, therefore, about the relative value and the feasibility of the various projects in the plan. This process is complex, involves many issues, and may actually include hundreds of individual decisions and judgments. Developing an I&M program requires technical information, personal knowledge, and judgments of resource managers. An analytical approach views I&M planning in an organized framework and incorporates valuable personal knowledge.

The approach described in this section is based on the I&M program objectives that were established in Silsbee and Peterson (1991). If alternative objectives are preferred, then establishing program objectives is the first step in the following process. If the objectives in Silsbee and Peterson (1991) are acceptable, then I&M program development proceeds in the following separate steps (Schmoldt et al. 1994):

Step 1. Identify I&M projects
Step 2. Prioritize projects
Step 3. Maximize program value over all projects implemented

First, decision makers identify potential I&M projects that fulfill program objectives. Second, these projects are prioritized based on their total contribution to the goals of the I&M program. These priorities represent the *value* that each project contributes to the total program. We use the Analytic Hierarchy Process as a systematic technique to establish those priorities. Third, budget and personnel constraints are incorporated into program planning, such that total program value over all implemented projects is maximized. This last step lends itself to an integer programming solution, where the decision variables are the projects (each with the value 1 (implemented) or 0 (not implemented)), the coefficients are the priority values for each project, and the minimal list of constraints includes budget and personnel time.

Using the Analytic Hierarchy Process as a framework for decision making and planning in I&M programs is described in the following section. We have included considerable background on the conceptual basis for this process for readers to better understand how the process is linked to I&M planning. Most park personnel need not be familiar with the technical details of the Analytic Hierarchy Process to appreciate how it assists with decision making and planning. The I&M regional coordinator is normally involved in operating the software for this process and works with park personnel to derive model inputs and evaluate model outputs.

Analytic Hierarchy Process

The Analytic Hierarchy Process (Saaty 1980) has been used for planning, resource allocation, and priority-setting in many situations: business (Ramanujam and Saaty 1981), energy (Gholomnezhad 1981), health (Dougherty and Saaty 1982), marketing (Dyer and Forman 1991), and transportation (Saaty 1977). The process is used to support decision making for many complex processes and is also appropriate for I&M planning. The advantage of this system is that it allows the decision makers to organize many decision criteria and judgments, weigh the relative contributions of each, and arrive at a final assessment that is consistent and defensible. The two key ideas of the Analytic Hierarchy Process are (1) using hierarchies to structure decision making and (2) applying judgment measures and formal mathematics to express and quantify individual preferences.

Hierarchies

Hierarchies are particularly powerful because (1) their component elements are arranged in a modular fashion, and they are modified more efficiently than a system constructed as a whole (e. g., development proceeds in parallel for a modular system), (2) they are more resistant to perturbations because changes are small and local, (3) they are flexible to addictions, so performance does not degrade drastically, and (4) they are parsimonious structures that arrange many elements in an economical way.

To construct a hierarchy, a primary goal (or focus) is placed at the top. The goal in Figure 2 is to select a possible career out of the list: brain surgeon, chimney sweep, lawyer, plumber, and realtor. The criteria that are used to make this decision are job security, income, job satisfaction, prestige, and likely success in reaching that career goal. Subordinate criteria may be placed below these criteria to extend the analysis in greater detail, but this single level of criteria is sufficient for the sake of example. The alternative careers compared are below the criteria. In general, the elements at each level are relatively independent, and one level influences the elements of the next higher level only. Saaty (1990b) describes a method for evaluating the relative contribution (priority) of the elements at one level of the hierarchy to the elements at the next higher level.

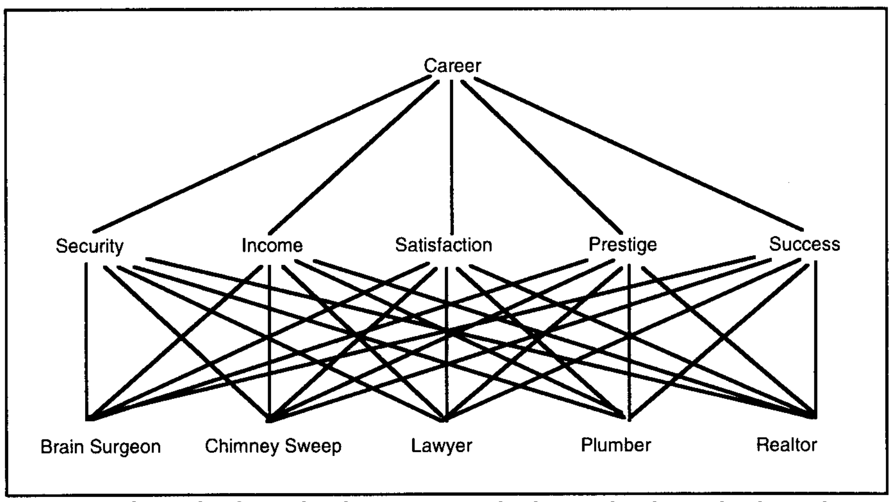


FIGURE 2. Hierarchy for selecting a career depicts selection criteria and alternative careers being evaluated.

Priority Measures

Events, places, and things are classified as desirable, important, or likely with respect to prior experience. These elements are, therefore, placed in relation to one another on some measurement scale, even if the measurement scale is not explicitly specified. By making pairwise comparisons of the influence of one element relative to another, a ratio scale emerges that captures the priority of these elements with respect to the comparison criterion. In the hierarchy in Figure 2, the amount of influence that any element of level *i* has for a property at level *i-1* (i.e., the next higher level) is determined by performing pairwise comparisons of all the elements in level *i*, with respect to the property of interest at level *i-1*. Those elements with a greater influence for the property possess a higher priority value with respect to that property. These comparisons are done for all elements of all nonleaf levels of the hierarchy. The alternatives present at the leaf level (e.g., the career choices in the lowest level in Figure 2) are then compared in a pairwise fashion with respect to their standing for each of the criteria at the next higher level. A matrix $\mathbf{A} = (a_{ij})$ $(ij = 1, \ldots . n)$ is constructed for all pairwise comparisons made at any level with respect to some property or criterion.

Each of the elements a_{ij} are thought of as a ratio w_i/w_j that indicates how much more important (or preferred or likely) element *i* is than element *j*. The vector w = [$w_1, w_2, \ldots, w_n$] contains the actual priority values (or weights) for each of the *n* elements that are compared. We estimate the weight vector w based on judgments regarding these ratios a_{ij}. Ratio judgments are taken from the scale (1, 3, 5, 7, 9), where intermediate values (2, 4, 6, 8) are also used. This scale is justified based on the work of Fechner (1966) on "just noticeable differences" and on the simultaneous comparison limit of 7 plus or minus 2 by Miller (1956). The ratio 1 indicates that the two elements are equal in that comparison and, of course, $a_{ii} = 1$. If element *j* is more important than element *i*, then $a_{ij} = 1/a_{ji}$. Saaty (1990b) demonstrates that the priority vector w is relatively unaffected by small changes from consistency in the judgments a_{ij} as long as none of the w_is become very small. Judgments deal with a *small* number of items that are relatively *comparable* to ensure the stability of an underlying ratio scale from pairwise comparisons.

"Small" is consistent with the social scientists' observation of 7 plus or minus 2 (Miller 1956), and "comparable" suggests that a scale with less than 10 values (one order of magnitude) are used. Consequently, the Analytic Hierarchy Process restricts the comparison matrix to 7 items and uses a 9-point judgment scale.

The Analytic Hierarchy Process provides a way to estimate and measure judgments on several alternatives with respect to particular criteria. However, we still are able to combine judgments regarding several criteria, each with its own influence (or priority).

The example in Figure 2 shows how this works. Table 3 contains the pairwise judgments about the criteria at level 1 in Figure 2 with respect to the goal, "Select a Career" at level 0. If a_{ij} *is* greater than 1 for element a_{ij} of the table, then the row heading is a_{ij} times more important than the column heading for selecting a career. The influence of the headings is reversed where a_{ij} is less than 1, that is, the column heading is $1/a_{ij}$ times more important than the row heading. We can then create similar tables comparing all of the career alternatives with respect to each criterion.

TABLE 3. Pairwise judgments compare job criteria with respect to their importance for selecting a career.

Career	Security	Income	Satisfaction	Prestige	Success
Security	1	3	2	3	1
Income	1/3	1	1/4	2	1/2
Satisfaction	1/2	4	1	3	1
Prestige	1/3	1/2	1/3	1	1/3
Success	1	2	1	3	1

Framework for I&M Planning and Prioritization

The Analytic Hierarchy Process allows the user to define the criteria for establishing priorities in a straightforward yet powerful way. For example, priorities may be set for some aspect of an I&M plan based on economic and biological factors. The user subdivides the biological factors into several subfactors, such as endangered species status, susceptibility to air pollution, and geographic distribution. The user then divides each of these subfactors into subfactors at a finer resolution. The hierarchical process continues for many levels to include all possibilities that are considered. Rankings are assigned within each level of the process. The structure of the hierarchy differs depending on the I&M topic in question. The linkages obviously become complex after only a few levels. Because such tedious calculations would distract an I&M planner from the important task of providing judgments and would make the entire procedure inefficient, the Analytic Hierarchy Process is incorporated into the software package Expert Choice (Expert Choice, Inc., Pittsburgh, Pennsylvania). The Analytic Hierarchy Process (in the form of Expert Choice) allows the user to apply hundreds of qualitative and quantitative assessments simultaneously to establish the linkages and to calculate the final rankings quickly and accurately, a task that cannot be done with pencil and paper (or calculator). The process allows a resource manager to explore the nature of the decisions that are used to establish priorities in I&M planning. The planning-knowledge database thus created may be revised and updated at any time, so it is a flexible tool for planning and decision making.

The computer version of the Analytic Hierarchy Process (hereafter referred to as AHP/EC) is operated with a minimum of training on a personal computer and is interactive with the user. Having one individual per region who is familiar with the software and operation of the program is preferable. This individual then participates with parks in prioritizing the I&M projects. AHP/EC permits planners and resource managers to systematically assess subjective judgments regarding preferences, priorities, or likelihoods; the process does not *make* decisions but *facilitates* decision making. The process assists with I&M planning to

- organize complexity
- incorporate quantitative information and knowledge and intuition
- consider trade-offs among competing criteria
- determine the best program alternatives
- communicate to others the rationale for a decision
- incorporate group judgments

AHP/EC provides a spreadsheet-like environment for *rating* each alternative with respect to each lowest-level criterion using the intensity scale developed for that criterion. These intensity scales abandon relative worth in favor of absolute measures. Therefore, rank reversals (the substitution effect) that may occur when a new alternative is introduced to the analyses are not possible (Forman 1987). The model does not provide an entirely objective approach to assigning ratings to projects. *Different users may get entirely different results,* depending on the priorities given to different objectives and criteria and the ratings assigned to each criterion for the individual projects. However, the model does force the user to recognize and quantify decisions about the importance of different objectives when one project is chosen over another. The model clarifies the trade-offs and sorts through different alternatives to make the ranking process more rational.

Model Structure

The model is structured as a hierarchical arrangement of (1) I&M objectives (at the highest level of the model), (2) criteria that are useful for rating projects with respect to each objective, (3) an intensity scale for rating each project with respect to each criterion, and (4) actual ratings for each project across all criteria.

The objectives are modified from those described by Silsbee and Peterson (1991) and are illustrated in Figure 3 and Table 4. They are assigned relative rankings in whatever way the user desires.

A complete spectrum of possible score assignments exists, including (1) an objective with maximum importance and all others with an importance of zero, (2) all objectives of equal importance, or (3) any combination of unequal rankings for different objectives. Projects that meet one objective well but not others are rated high when that objective is important relative to the others; they are not rated high if that objective is less important. Three subobjectives are specified for the major objective, "understand ecosystem function" in Figure 3; these are ranked relative to their contribution to this major objective. The subobjectives are then treated similarly to the remaining objectives in the model.

For each objective in the model, 1 to 4 *criteria* describe how well a project meets the objective. The user must assign 1 of 5 rating scores to each project for each criterion. The scores are given descriptive names (e.g., extremely important, moderately important, etc.), but they are really just numerical scores ranging from satisfying the criterion extremely well to not satisfying it at all. In many cases, applying judgments based on word descriptions rather than assigning numerical values is easier; either method may be used. In assigning scores, the user judges more on how well the project meets the criterion than trying to make the project fit the words used in the model.

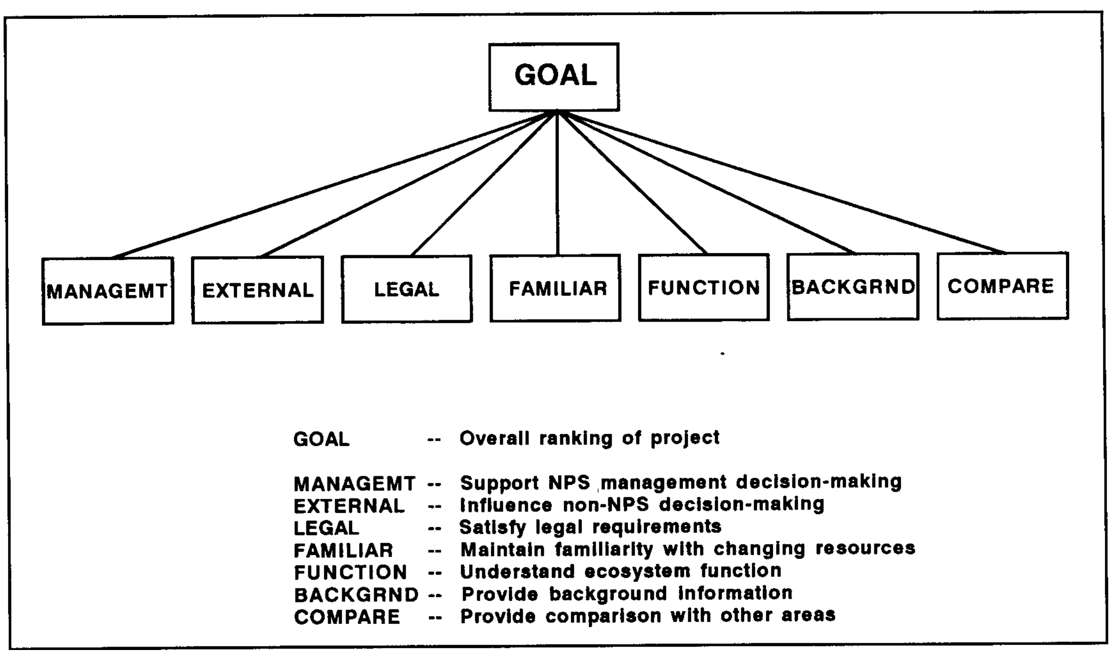


Figure 3. Top level of I&M hierarchy contains seven objectives. Abbreviated terms in the figure are explained in the legend.

TABLE 4. *Seven objectives of top level of I&M hierarchy.*

Objective 1: Support Management Decision Making

The three most important criteria for determining how well a project supports management decision making are (Figure 4):

1. How important the decision is for which the project supplies supporting data
2. How badly the data are needed to make an informed decision
3. How well the project provides the data needed for the decision

Objective 2: Influence External Decisions Relevant to Park Management

The three most important criteria for determining how well a project provides data to support non-NPS decision making relevant to park management are (Figure 5):

1. The importance of the decision to the park
2. The potential for park managers to influence the decision
3. The degree to which information from the project increases the influence of the National Park Service over the decision

Objective 3: Satisfy Legal Mandates

The two most important criteria for determining how well a project satisfies existing or potential legal requirements are (Figure 6):

1. The degree to which legal mandates are binding requirements
2. Whether data from the project is sufficient to satisfy the legal mandates

Objective 4: Maintain Familiarity with Park Resources

This objective is the first of three that are relevant to I&M activities that give resource managers a better understanding of natural resources. The four most important criteria for determining how well a project helps managers stay familiar with the resources with which they work are (Figure 7):

1. The importance of the resource involved in the project
2. Whether the resource is changing
3. The amount of current knowledge of the resource
4. The degree to which the project fills gaps in current knowledge

Objective 5: Understand Ecosystem Function

This objective is the second of three that are relevant to I&M activities that give resource managers a better understanding of natural resources. The three most important criteria for determining how well a project helps improve understanding of ecosystem function are (figure 8):

1. The importance of the resource involved in the project
2. The amount of current knowledge of the resource
3. The degree to which the project considered fills in gaps in current knowledge

Objective 6: Provide Background Information for Use by Other Projects and Programs

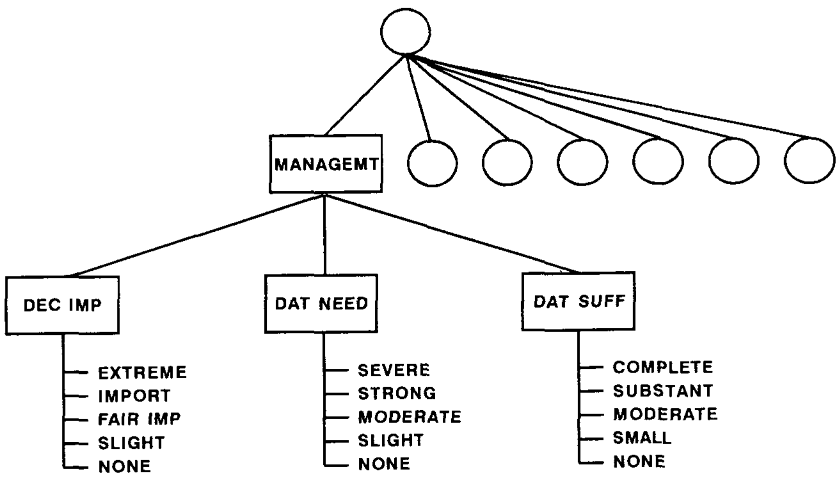
This objective is the third of three that are relevant to I&M activities that give resource managers a better understanding of natural resources. The most important criterion for determining how well a project provides useful background material is (Figure 9):

1. How useful the information will be

Objective 7: Provide Background Information Against Which Areas Outside the Park are Compared

The three most important criteria for determining how well a project helps provide background information for other areas are (Figure 10):

1. The regional importance of the resource involved in the project
2. The comparability of the resources and areas compared
3. The usefulness of the project for providing a warning about changes in resource conditions at the regional scale



MANAGEMT -- Support NPS management decision-making

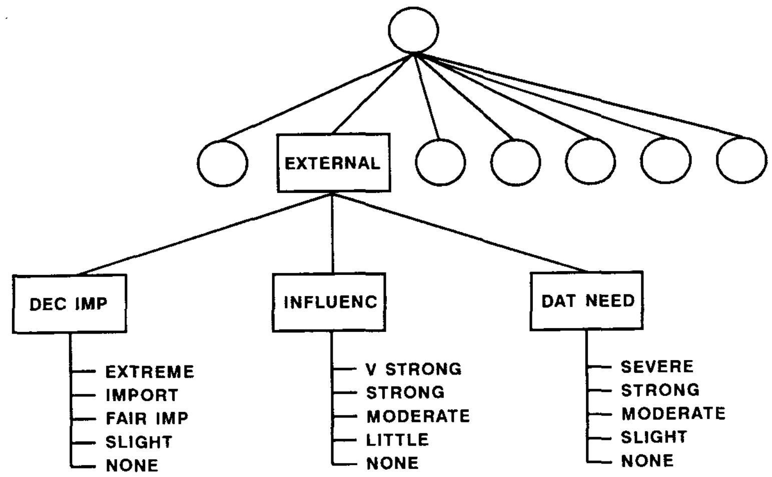
DEC IMP -- How important is the decision?
DAT NEED -- How badly are data needed to support a decision?
DAT SUFF -- Are data from the project sufficient for the decision?

EXTREME -- Extremely important
IMPORT -- Important
FAIR IMP -- Fairly important
SLIGHT -- Slightly important
NONE -- Not important

SEVERE -- Severe need for data
STRONG -- Strong need for data
MODERATE -- Moderate need for data
SLIGHT -- Slight need for data
NONE -- No need for data

COMPLETE -- All needed data will be provided
SUBSTANT -- Most needed data will be provided
MODERATE -- A moderate amount of needed data will be provided
SMALL -- A small amount of needed data will be provided
NONE -- No needed data will be provided

FIGURE 4. First objective in I&M hierarchy contains three criteria, each with a corresponding rating scale.



EXTERNAL -- Influence non-NPS decision-making

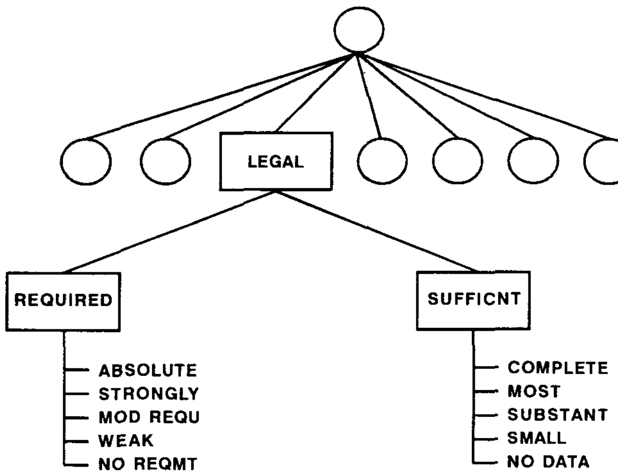
DEC IMP -- How important is the decision?
INFLUENCE -- What is the potential for influencing the decision?
DAT NEED -- How much are data needed to influence the decision?

EXTREME -- Extremely important
IMPORT -- Important
FAIR IMP -- Fairly important
SLIGHT -- Slightly important
NONE -- Not important

V STRONG -- Very strong influence
STRONG -- Strong influence
MODERATE -- Moderately strong influence
LITTLE -- Little influence
NONE -- No influence

SEVERE -- Severe need for data
STRONG -- Strong need for data
MODERATE -- Moderate need for data
SLIGHT -- Slight need for data
NONE -- No need for data

FIGURE 5. Second objective in I&M hierarchy contains three criteria, each with a corresponding rating scale.



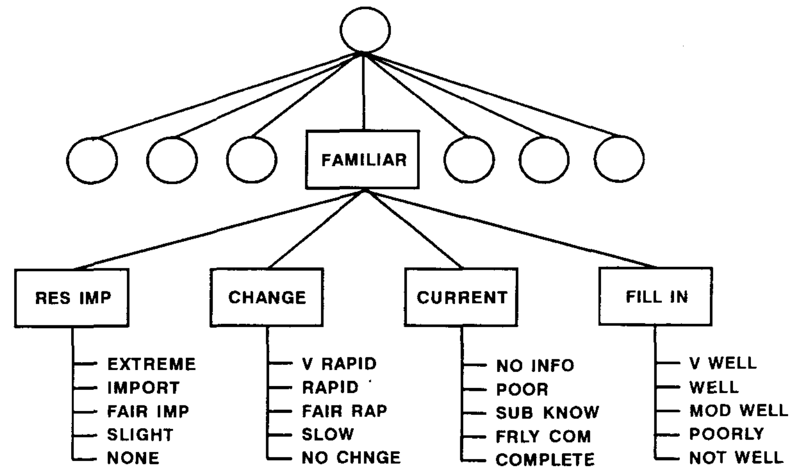
LEGAL -- Satisfy legal requirements

REQUIRED -- Is project required by law?
SUFFICNT -- Is project sufficient to satisfy legal requirement?

ABSOLUTE -- Project absolutely required by law
STRONGLY -- Legal requirement is quite strong
MOD REQU -- Only a moderate legal requirement
WEAK -- Project satisfies only a weak legal requirement
NO REQMT -- No legal requirement

COMPLETE -- Complete -- no further data needed
MOST -- Provides most needed data
SUBSTANT -- Provides a substantial amount of needed data
SMALL -- Provides only a small amount of needed data
NO DATA -- Does not provide data for legal purposes

FIGURE 6. Third objective in I&M hierarchy contains two criteria, each with a corresponding rating scale.



FAMILIAR -- Maintain familiarity with changing resources

RES IMP -- How important is the resource?
CHANGE -- Is resource in a state of change?
CURRENT -- How complete is current knowledge of the resource?
FILL IN -- How well will this project fill in gaps in knowledge?

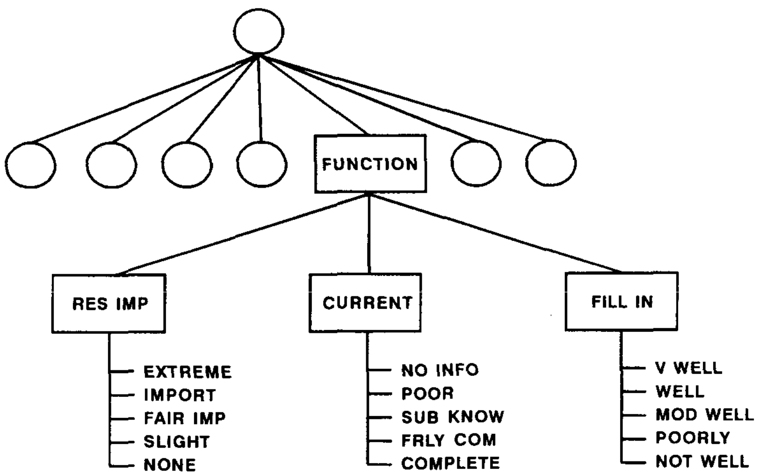
EXTREME -- Extremely important
IMPORT -- Important
FAIR IMP -- Fairly important
SLIGHT -- Slightly important
NONE -- Not important

V RAPID -- Change is very rapid and potentially drastic
RAPID -- Change is rapid and significant
FAIR RAP -- Change is fairly rapid and potentially significant
SLOW -- Change is probably slow or unimportant
NO CHNGE -- No change expected

NO INFO -- No information currently exists concering this resource
POOR -- Current knowledge is poor
SUB KNOW -- Substantial knowledge of resource exists
FRLY COM -- Fairly complete -- resource is well understood
COMPLETE -- No further data needed

V WELL -- Data will supply missing pieces very well
WELL -- Data will fill gaps well
MOD WELL -- Data will fill gaps moderately well
POORLY -- Data will not fill gaps or will duplicate existing knowledge
NOT WELL -- Data will not add new knowledge

FIGURE 7. Fourth objective in I&M hierarchy contains four criteria, each with a corresponding rating scale.



FUNCTION -- Understand ecosystem function

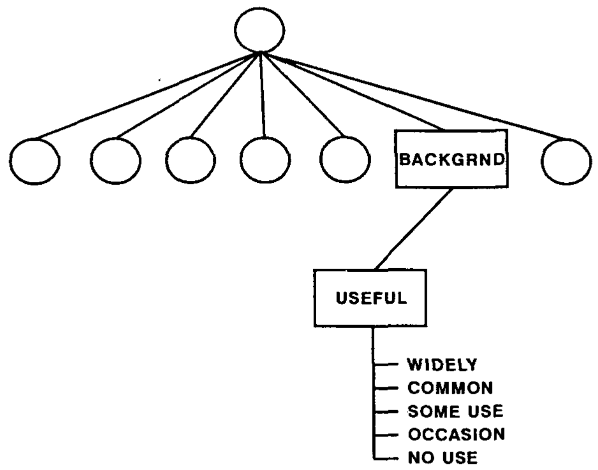
RES IMP -- How important is the resource?
CURRENT -- How complete is current knowledge of the resource?
FILL IN -- How well will this project fill gaps in knowledge?

EXTREME -- Extremely important
IMPORT -- Important
FAIR IMP -- Fairly important
SLIGHT -- Slightly important
NONE -- Not important

NO INFO -- No information currently exists concerning this resource
POOR -- Current knowledge is poor
SUB KNOW -- Substantial knowledge exists concerning resource
FRLY COM -- Fairly complete: resource is well understood
COMPLETE -- No further data needed

V WELL -- Data will supply missing pieces very well
WELL -- Data will fill gaps well
MOD WELL -- Data will fill gaps moderately well
POORLY -- Data will not fill gaps or will duplicate existing knowledge
NOT WELL -- Data will not add new knowledge

FIGURE 8. Fifth objective in I&M hierarchy contains three criteria, each with a corresponding rating scale.



BACKGRND -- Provide background information

USEFUL -- How widely will the information be used?

WIDELY -- Data will be widely used for many applications
COMMON -- Data will be commonly used
SOME USE -- Information will be used for some applications
OCCASION -- Information will only occasionally be used
NO USE -- Information will not be used

FIGURE 9. Sixth objective in I&M hierarchy contains one criterion. with a corresponding rating scale.

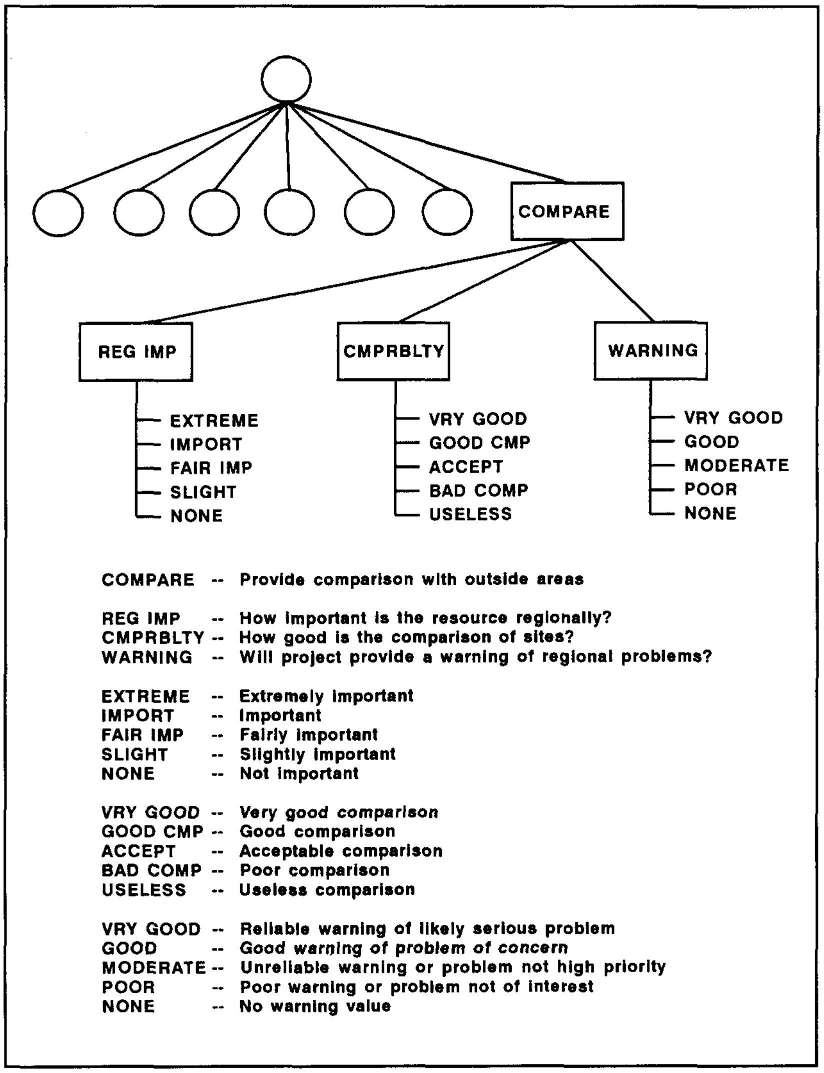


FIGURE 10. Seventh objective in I&M hierarchy contains three criteria, each with a corresponding rating scale.

time, are considered. A linear programming approach maximizes the total program value, subject to constraints. Although the combination of the Analytic Hierarchy Process and linear programming has been used before (Saaty and Kearns 1985, Saaty 1986), we formulated our approach independently.

This constrained optimization situation is a zero/one integer programming problem. Each of the projects x_i is either implemented (1) or not implemented (0) in an I&M program. A solution describing an I&M program consists of the vector $\mathbf{x} = [\ x_1, x_2, ..., \ x_n]$, where each x_i is either 0 or 1. The value of each project w_i for the total I&M program is taken from the weight vectors that are estimated using the Analytic Hierarchy Process. Each project also has a budget requirement c_i and a requirement for a certain number of full-time employee (FTE) years t_i. The resulting formulation is:

$$\text{maximize } Z = \sum_{i=1}^{n} w_i x_i$$

$$\text{subject to: } \quad \sum_{i=1}^{n} c_i x_i \leq \text{Total Budget}$$

$$\sum_{i=1}^{n} t_i x_i \leq \text{Total FTE's}$$

Integer Programming Model

Each project is given a value score indicating its contribution to the goals of an I&M program. Each project also requires some expenditure of I&M program resources, that is, money and personnel. Therefore, implementing projects only on the basis of their values does not necessarily make the most effective use of program resources. Using a benefit-cost ratio as the selection criterion for such resource allocation problems (Saaty 1980, Saaty 1987, Saaty 1990a) is possible. Project selections having the best economic payoff are then the most desirable. However, the goal of I&M planning is the most work for the given budget and personnel limitations, where “most” is defined as the greatest total program value. In addition, the benefit-cost approach does not apply when other program resource constraints, such as personnel

This value represents the minimum number of constraints that is important. Managers can also include other constraints, such as restrictions on the timing of projects. For example, if a particular project to analyze snow chemistry (project 30) is not performed until a geographic survey of snow accumulation is completed (project 42), then the constraint $x_{42} \geq x_{30}$ is added to the previous formulation.

As in any optimization problem, the result is only as realistic as the parameter values that are used in the calculations. More accurate budget or personnel estimates or revised value judgments change the resulting I&M program. Iterative use of this planning process ensures that the results are stable and acceptable. The following example illustrates how this I&M planning process incorporates the Analytic Hierarchy Process and constrained optimization.

Example of Prioritizing I&M Projects

The previous section described the model structure for I&M decision making and planning with respect to project priorities and program optimization. To illustrate how AHP/EC is used to calculate the rankings, we developed an example using projects that are a part of a park I&M program. The intention is to have a realistic range of projects, with different scores for different objectives, and to establish project priorities for potential management scenarios.

Twelve projects are used in the exercise (Table 5), as follows:

1. Status of rare plant populations
2. Ambient ozone concentrations (air quality)
3. Status of large mammal populations (wildlife)
4. Status of anadromous fish populations
5. Damage to alpine plants from hikers and campers
6. Maintenance of weather stations for collecting meteorologic data
7. Wet and dry acidic deposition (atmospheric deposition)
8. Nutrient cycling characteristics in a specific watershed
9. Avalanche forecasting in avalanche-prone areas
10. Collection and maintenance of herbarium specimens
11. Salmon carcass availability for bears and eagles
12. Snowpack depth in various watersheds

We made pairwise comparisons among all of the objectives with respect to the I&M program goal, and we made pairwise comparisons among criteria with respect to each objective. We assigned scores for all of the criteria in all of the objectives of the prototype model for each I&M project. These comparisons and rating scores are not listed here and are not critical for this discussion. The scores were assigned to maintain reasonable consistency for this exercise. The prototype model was used to rank the projects under five different scenarios with respect to the importance of the model objectives: (1) all objectives equal, (2) "support of management decision making" as the highest priority (but other projects having some priorit y), (3) "support of management decision making" as the only objective, (4) "influence on external decision makers" as the highest priority (but other projects having some priority), and (5) "influence on external decision makers" as the only objective. Thousands of scenarios are possible, but these examples illustrate the responsiveness of the model to the different objectives.

Project rankings for the different scenarios are shown in Table 5. The table includes the summary numerical ratings (with a maximum value of 1) and the ordinal rank for each project. The ratings are weighted scores for each project summed over all of the criteria. If a particular project scored highest on all of the criteria, then that project would have the maximum value of 1. We can normalize these rating values, but without loss of validity we have elected to leave them in their present form. "Status of rare plants" is the high priority project when all the objectives have equal importance, and has even a higher priority (as indicated by the numerical score) when "support of management decision making" has the highest priority. However, this project drops to fifth when "support of management decision making" is the only objective; "status of large mammal populations" (wildlife) then has the highest priority. Model output for two additional scenarios in the table illustrates two different sets of rankings for the I&M projects.

This example shows that project importance varies considerably, based on the relative importance of the various model objectives. Furthermore, the prototype model also has considerable sensitivity to the criteria scores that are used in the example. Rankings are shown to vary on both a relative (ordinal) and absolute (numerical) basis. Because we believe that this example is realistic, we expect similar model sensitivity in most I&M planning situations.

TABLE 5. Different scenarios of importance for eight objectives of the model produce different project ratings and rankings.

Project	All Objectives Equal		Management has Highest Priority		Management Only		External Influence has Highest Priority		External Influence Only	
	Rating	Rank	Rating	Rank	Rating	Rank	Rating	Rank	Rating	Rank
Rare Plants	0.63	1	0.63	1	0.64	5	0.60	2	0.50	4
Air Quality	0.60	2	0.48	5	0.00	10	0.64	1	0.80	1
Wildlife	0.49	3	0.56	2	0.82	1	0.51	4	0.60	3
Fish Status	0.48	4	0.52	3	0.70	4	0.52	3	0.70	2
Alpine Plants	0.46	5	0.51	4	0.76	2	0.36	6	0.00	10
Weather Stations	0.40	6	0.42	6	0.52	6	0.33	7	0.07	8
Atmospheric Deposition	0.38	7	0.30	8	0.00	10	0.38	5	0.40	6
Nutrient Cycling	0.35	8	0.30	9	0.10	9	0.32	8	0.20	7
Avalanche Forecast	0.31	9	0.40	7	0.76	2	0.24	10	0.00	10
Herbarium	0.28	10	0.22	12	0.00	10	0.22	11	0.00	10
Salmon Carcass	0.26	11	0.25	10	0.22	7	0.30	9	0.50	4
Snowpack	0.24	12	0.23	11	0.22	7	0.20	12	0.03	9

Allocating I&M Program Resources

Continuing with the I&M example in the previous section, the resource allocation portion of the planning problem is formulated. Priority values from the AHP exercise are estimated as coefficients in the integer programming objective function. Table 6 contains the coefficients for the two constraint equations; the values in the table are used as coefficients in integer programming constraint equations. Budget and FTE values for each of the 12 projects were borrowed from the 1990 Olympic National Park Resource Management Plan. The total budget expended for 38 funded projects in 1990 was $860,700, and the total FTE allocation was 21.8. We calculated the appropriate proportion to approximate these figures for our example with the 12 projects. Integer programming solutions for each of the different scenarios of Table 5 are summarized in Table 7, given a total budget of $271,800 and 10.60 FTE years. Total I&M program values are listed in the last row of the table.

TABLE 6. Budget and FTE values from 1990 Olympic National Park Resource Management Plan.

Project	Project Cost ($1,000)	Project FTE (Person-Years)
Rare Plants	24.0	0.70
Air Quality	96.5	0.30
Wildlife	57.5	1.75
Fish Status	41.0	1.75
Alpine Plants	17.5	1.00
Weather Stations	42.8	0.10
Atmospheric	42.0	1.40
Nutrient Cycling	150.0	2.20
Avalanche Forecast	5.5	0.15
Herbarium	15.4	0.41
Salmon Carcass	35.0	0.80
Snowpack	8.3	0.04
Total Available	271.8	10.60

Comparisons of the total program value across the different scenarios are not valid. Priority ratings that depend on different program objectives determine program values. These numbers are provided for comparison between optimal and near-optimal allocation within each scenario.

The I&M programs displayed in Table 7 are optimal based on the priorities that are assigned to the I&M objectives and criteria on the ratings of each project with respect to criteria intensities, and on the constraint coefficients that are provided. Rare plants and wildlife projects are implemented in all programs of Table 7. Each project has high value to an I&M program and has low-to-moderate cost. Nutrient cycling, on the other hand, has low-to-moderate value to inventory and monitoring and has a high requirement for I&M resources. The near-optimal program is within 10% of the optimal program in all cases. Therefore, a near-optimal program is used to reserve some budget and personnel time without a substantial loss in I&M capability. Assuming reasonably accurate estimates for project costs and full-time employees, successive steps in this planning process revise criteria importance or project ratings and then examine their effects on optimal I&M programs.

Applications in I&M Planning and Decision Support

The example deals with only a small number of I&M projects, but the outcome of this analysis highlights some important issues. The substantial differences in I&M programs that result from different program objective emphases suggest that national parks must clearly identify (1) the uses of inventory and monitoring and (2) the objectives for the park with respect to the larger issue of resource management planning. The proposed planning process offers a framework in which I&M and resource management planning issues are explicitly addressed and quantified.

TABLE 7. Integer programming decision variables indicate implemented (1) projects and nonimplemented (0) projects. The different scenarios of importance for the eight management objectives result in different optimal selections of projects to implement. One near-optimal program is also included for each scenario.

Project	All Objectives Equal		Management has Highest Priority		Management Only		External Influence has Highest Priority		External Influence Only	
	Optimal Program	Near-Optimal Program	Optimal Program	Near-Optimal Program	Optimal Program	Near-Optimal Program	Optimal Program	Near-Optimal Program	Optimal Program	Near-Optimal Program
Rare Plants	1	1	1	1	1	1	1	1	1	1
Air Quality	0	0	0	1	0	0	0	1	1	1
Wildlife	1	1	1	1	1	1	1	1	1	1
Fish Status	1	0	1	1	1	1	1	1	1	1
Alpine Plants	1	1	1	1	1	1	1	1	0	0
Weather Stations	1	1	1	0	1	1	1	0	0	0
Atmospheric Deposition	0	1	0	0	0	1	0	0	0	0
Nutrient Cycling	0	0	0	0	0	0	0	0	0	0
Avalanche Forecast	1	1	1	1	1	1	1	1	0	0
Herbarium	1	1	1	1	0	0	1	1	0	0
Salmon Carcass	1	1	1	0	1	0	1	0	1	1
Snowpack	1	1	1	1	1	0	1	1	1	0
Program Value	3.531	3.430	3.748	3.551	4.640	4.200	3.300	3.298	3.133	3.100

One of the most valuable aspects of AHP/EC is the ease with which users can change various components in order to see the effect on the model output. Values are changed randomly or systematically to determine how modifications in the objectives would change the I&M priorities. For example, the relative importance of an I&M project in "support of resource management decision making" can be high in one case but low in another. Or an emphasis on "satisfy legal mandates" can replace an emphasis on "support of resource management decision making. " The relative change in the I&M project rankings indicates the sensitivity of the model for current inputs. Making large or small changes shows the effect of changing the emphasis of the objectives and the individual criterion scores. This exercise also allows a manager to determine how different management objectives affect the overall rankings; one project can be favored, and one or more other projects dropped in priority.

Mathematically estimating inconsistencies in judgment, when making pairwise judgments using the Analytic Hierarchy Process, is possible. AHP/EC calculates a value that indicates whether an inconsistent pattern of judgments is borne out by the user's pairwise rankings. Inconsistencies are sometimes appropriate, and the capability of the model to detect them allows the user to decide whether they should be retained. In some cases, a park can have a strong interest in one particular I&M project, or perhaps a park can support only a few projects. The huge amount of information contained within the AHP/EC model structure permits a resource manager to examine the conceptual basis for an I&M project in great detail. Branches and decision structures are added as necessary for an individual project without affecting other project evaluations. Components are added or deleted and criteria changed as necessary for different situations. Although the current form of the model is preliminary, a reasonably fixed model structure is preferable as the basis for future I&M planning. Considerable model testing is recommended before the model structure is determined.

Most national parks have at least a few components of resource management that are categorized as inventory and monitoring. Many parks have a long list of proposed I&M projects, although only a few of them are authorized or funded. The prototype model allows managers to list all of their proposed I&M projects, then evaluate them with respect to technical information and their own personal judgment. Rankings for the example used in this paper are based on existing information and knowledge, with a minimum of personal bias about political or other issues.

Although one person administers an I&M program, several people normally provide input for developing the program. Because so many pieces of information and decisions are involved in developing a coherent program, obtaining a consensus is difficult. The AHP/EC model integrates divergent opinions by calculating mean values for each component of the model. The final ranking is then truly the result of group input; the ranking does not reflect the bias of one individual or require anyone in the group to mediate or make a final judgment. Ratings from individuals are balanced if that is desirable, perhaps with extra consideration given to subject-matter experts for different resource areas.

Inventory and monitoring is currently just one component of a resource management plan of most national parks and may or may not be identified as a discrete program within a park's plan. The size of resource management plans and I&M programs varies greatly, depending on park size and resource diversity. In any case, the evaluation and prioritization that are required for developing a resource management plan are nearly identical to those required for an I&M program, except on a larger relative scale. Because of the parallels between resource management plan development and I&M planning, we believe that the prototype model (or similar AHP approach) also provides an analytical framework for resource management planning, especially for ranking project priorities.

Resource management projects of many kinds are often closely tied logically and practically over several years. Using a multi-year horizon for planning is important. Our example has not explicitly included this aspect of planning, but can easily accommodate multi-year projects. Decision variables are indexed by planning yearly projects. Projects are funded when they become most important for the specified plannin objectives.

The I&M planning tool described here is not intended to *make* decisions for resource managers but to *assist* them in making decisions. Resource management planning and I&M planning are complex and will never be a turnkey process. The process is improved, however, by making it more explicit, rational, analytical, defensible, and consistent.

Quality Assurance and Data Management

I&M projects require careful attention to ensure the quality of the data collected. Quality assurance (QA) provides continuity and consistency, which are particularly crucial when data are collected by a variety of people over a long period of time. Quality assurance for an I&M program is concerned with designing a program that meets the stated objectives and with identifying, addressing, and resolving potential problems. The project may or may not require particular experimental designs or methods, but thoroughly documenting the project objectives, design, and methods is always necessary. Quality assurance also requires documenting the precision and accuracy of all the types of measurements made. A strong QA program is the cornerstone of credibility for an I&M program and will ensure that the data will stand up in a court of law if necessary.

Each I&M project normally requires special considerations. The I&M coordinator for each park is aware of QA concerns and addresses them explicitly. Working with a statistician on the study design, sampling, and statistical analysis is advisable. Contacting scientists with expertise in quality assurance to develop protocols for park projects is also important. Advice on specific QA protocols is obtained through NPS divisions, such as the Air Quality Division and the Water Resources Division. Other agencies, particularly the Environmental Protection Agency, also have considerable expertise in this area.

Only the most important aspects of quality assurance are discussed in this section, and some general guidelines are offered. These guidelines nearly always require some modification for specific circumstances. This section is not a comprehensive summary of QA issues or protocols with respect to data collection.

Quality Assurance Plans

Every funded I&M project (i.e., not every project in the I&M plan) contains a detailed study plan that includes a QA plan.

Subject-matter experts from appropriate fields review the QA plan for technical rigor. A statistician and other individuals with QA expertise also review the QA plan. Elements of the QA plan are described.

A QA plan includes:

1. A description that explains and justifies the overall approach to the project:

- *a clear statement of objectives, including how the data will be used*
- *a general description and justification of study methods*
- *population of inference and geographic area*
- *statistical approach*
- *related studies and data sets*

2. A methods manual:

- *site selection criteria and methods*
- *sampling protocols, in sufficient detail for project personnel to use as a manual*
- *data sheets for recording data*
- *methods and schedule for calibrating and maintaining instruments*
- *methods of documenting precision and accuracy of measurements*
- *data analysis and reporting methods to be used*

Project Description

The project description states the objectives and clearly demonstrates how the project will collect information to meet the stated objectives (Brossman et al. 1985). The project description includes enough detail for reviewers to evaluate whether the overall study design is appropriate and provides a framework for discussing specific methods.

Objectives. Project objectives are more than just a general statement of purpose. They include specific hypotheses to be tested, estimates of the precision of the results (required for parameter estimates), statistical power (for statistical tests and trend detection), and the time frame within which each objective is to be accomplished (Hinds 1984).

Methods. Study methods, including a brief overview, are described in detail in a methods manual. This section focuses on describing the overall strategy, rather than detailing the specific protocols. This section includes a list of parameters that are measured and the methods for measuring them (Brossman et al. 1985). This section also states why the parameters meet the project objectives and why the methods are the most appropriate ones.

Special attention is given to evaluating whether the resulting estimates of the various parameters will provide the best and most appropriate type of data. For example, collecting precise, accurate, well-documented ozone concentration data is not particularly useful if the monitoring site is not representative or the time frame of sampling is not relevant to park objectives.

Scope. The population of inference (or target population) relative to the project objectives is clearly stated. For example, if the project involves monitoring forest vegetation, is the objective to detect trends in vegetation (1) throughout the park, (2) only for selected vegetation types, (3) only in selected geographic areas, or (4) only in areas affected by a particular environmental factor? If the project involves monitoring air pollution, is the objective to (1) measure the quality of the air entering the park from particular urban areas, (2) detect possible exceedances of the national ambient air quality standards, or (3) estimate the exposure of plants to air pollution? Differences in the scope of a project clearly affect the methods and sampling approaches.

Statistical Treatment. Statistical analysis is an integral part of a project design, and appropriate methods are designated *before any data are collected* (Liggett 1985). Modifications are made after data collection, but a preliminary plan for data analysis is necessary to identify an appropriate sampling strategy. Particular attention is given to summary statistics, how samples will be grouped for analysis, spatial or treatment comparisons, statistical tests, and temporal or time series analysis. Constraints on the sampling strategy and analytical approaches are discussed.

Relationship to Other Studies. The relationship of a project to other studies and data sets inside and outside the park is described. Linkages with ongoing data collection efforts and data compatibility are particularly important. If comparisons are made with other results, then the comparability of the methods and sites are evaluated. The availability of the supporting data needed for analysis (e.g., weather data) is addressed. Any studies relevant to the design of the current study are mentioned.

Methods Manual

The methods manual details all the methods that are used in a project. This manual is detailed and referenced, so reviewers can evaluate the methods. The methods manual is an important source of information throughout the life of a project and provides guidance for current and future project personnel. Discussions are clear so that methods may be duplicated without confusion. Diagrams, tables, maps, and photos illustrate the methodology.

Site Selection. Documenting site selection varies somewhat according to the project. A simple description of how sites are selected is sufficient for projects such as vegetation inventories, in which a large number of sites are selected over the course of a project. This description includes the criteria used for identifying acceptable sites and the methods used in locating sites. Only one or a few sites are used for projects such as air quality monitoring. The project manager selects these sites at the beginning of a study. In this case, actual sites are identified rather than the methods of selecting the sites. Maps are extremely important for describing the site locations and are used in conjunction with geographic coordinates and an on-the-ground description.

Sampling Protocols. The methods manual includes a complete description of the sampling procedure for each parameter that is measured (Brossman et al. 1985). This description either references published standard operating procedures or the detailed descriptions of the procedures. If the description is written by referencing these materials, copies of the referenced procedures are made for anyone involved in the project. In either case, descriptions of all the data that are collected are included.

For field measurements, the standard operating procedure includes instructions for performing the measurements under normal circumstances, instructions on dealing with any potential exceptions, and descriptions of the equipment. Describing the simple procedure of measuring a tree diameter at breast height (dbh) (Zedaker and Nicholas 1990) includes more detail than just “measure the tree’s diameter at 1.37 m above the ground. ” The dbh description also indicates which side of the tree to stand on, how to document exactly where the measurement is made, and what to do about stem abnormalities. The methods manual ‘also describes the tape that is used for the measurements, how to use it, and how to take care of it.

The sampling procedure for the samples brought to the laboratory for analysis is described in the same detail as that for the field measurements. Instructions on how the samples are treated after collection are included. Details are needed on how long samples can wait before analysis, any required storage conditions (e.g., refrigeration, dry location), any necessary preservation, and other required treatments (Brossman et al. 1985). Data sheets include spaces to document that these conditions are met.

Laboratory procedures are documented in detail, similar to that used for field measurements, either directly or by referencing standard operating procedures that are readily available to project personnel (Taylor 1985).

Using analyzers, dataloggers, and other electronic instruments, whether in the laboratory or in the field, requires a somewhat different level of documentation. The same sort of detailed procedures for all the actions that an operator performs are provided, and procedures for *documenting* the instrument's proper operation are included (Lockhart 1985). This documentation is discussed under the Calibration and Maintenance section.

Data Sheets. Data sheets include spaces for all data that are consistently collected over the course of a program, including space for comments. Dataloggers and computers record data in the field and in the laboratory, and the data formats and operating procedures are documented.

Calibration and Maintenance. A schedule of calibration and preventive maintenance procedures are included for instruments with instructions (or references to instructions) for all procedures (Brossman et al. 1985). Instrument manuals provide much of this information, and a simple schedule, along with appropriate references to the operator's manual, is sufficient. A log book is used to document when calibration and maintenance activities are conducted and to note other observations that are relevant to instrument use.

Documenting Precision and Accuracy. Documenting the precision and the accuracy of the measurements is a critical aspect of quality assurance. All measurements made during a project have precision and accuracy information associated with them. *Precision* is the degree to which repeated measurements of a quantity vary from one measurement to another. *Accuracy* is the degree to which measurements differ from a true value (Mitchell et al. 1985). A number of factors influence the precision and accuracy of the measurements including (1) the precision and accuracy of the measuring tools and instruments, (2) the abilities of the individuals using the tools, and (3) the care and attention with which the measurements are made under the variable conditions of day-to-day operations. Separating these factors to evaluate data quality is not necessary but is useful in trying to improve data quality.

The basic approach to evaluating the precision of the measurements is to periodically repeat a small proportion of the measurements. This approach is easily performed in a laboratory setting by submitting a certain proportion of samples for a second analysis (Campbell and Scott 1985); however, this approach is more difficult to organize in a field measurement setting. Zedaker and Nicholas (1990) suggest monthly checks of precision and accuracy of measurements, such as dbh, in a special field exercise dedicated to quality assurance. Periodic QA checks adequately evaluate the tools that are used and the skills of those using them, but may fail to address the care with which the tools are used in a routine day-to-day setting or under the adverse conditions often found in the field. Care and attention to field measurements after weeks of repeating the same procedures limit data quality. A monthly test that everyone recognizes as a test does not necessarily evaluate the quality of routine field measurements, but QA checks are incorporated into the day-to-day field sampling operations in the same ways that they are used in a laboratory. For example, a second person repeats a certain percentage of the measurements without identifying the measurements in advance. The first person making the measurements is not aware of which measurements are checked.

The accuracy of the measurements is evaluated by comparing them with known true values. This comparison is relatively simple in a laboratory setting. The National Bureau of Standards has a series of standard reference materials that are designed to provide a "true" value for a wide variety of measurements (Alvarez 1985). Other sources, including the Environmental Protection Agency and commercial laboratory supply companies, produce reference samples that are "traceable to the standards of the National Bureau of Standards" (Eggenberger 1985, Winter 1985). These standards are used both for routine instrument calibration and for accuracy checks in a laboratory. Accuracy checks are conducted by inserting samples of known concentration into the stream of samples for analysis. As with precision checking, the person conducting the analysis does not know that a sample is a QA sample rather than a routine measurement.

Evaluating the accuracy of field measurements is more difficult. A standard reference tree for dbh and height measurements does not exist. Developing a procedure for repeating routine measurements without field personnel being aware of QA checks is difficult. The following two methods are possible:

1. Periodic QA sessions in which field personnel perform a series of measurements that have been carefully checked to determine the true value.

2. Repeat measurements during routine operations in ‘which the person performing the original measurement is unaware that it is used as a QA check; the person repeating the measurement does know and performs the measurement carefully.

The first method gives a more accurate true value and is less of a burden on field operations, but this method fails to account for the differences in the performances between routine operations and known testing situations. The second method checks the quality of the actual data instead of using an artificial test environment, but the true value with which the data are compared is more subject to measurement error. The first method is best for evaluating errors caused by problems with equipment or the skill level of personnel. The second method evaluates error from carelessness, fatigue, and other human characteristics. Field personnel use the first method in combination with QA checks of the instruments before sampling. The second method is used for evaluating the accuracy of the data.

In practice, checks on precision and accuracy are often combined into a single check. Repeating air quality measurements for precision checking is impossible because air concentrations fluctuate, and the sample is not available for a repeat measurement. However, a known (National Bureau of Standards traceable) standard concentration is measured on a regular basis (generally daily or weekly). The precision and accuracy elements are separated after-the-fact when analyzing the data. Precision is the variability in how well the known concentration is measured, and accuracy is the average difference between the measurement and the known concentration. Similarly, if 5 % of the dbh measurements are checked by a second person who uses a high standard of care in their measurement (the “true measurement “), the precision and accuracy are evaluated from the same data set. Precision is the variability of the difference in measurements; accuracy is the average difference.

Performing consistent QA checks on all types of measurements may be impractical. The precision and accuracy of some measurements are more critical than others, and the QA plan should reflect this difference. If personnel map all trees on a plot and measure their dbh and height, precision and accuracy information for dbh and height measurements are far more useful than the distance and azimuth used to map the sample trees. Dbh and height are the measurements to be summarized, analyzed, and compared with future samples. Project coordinators determine which variables merit QA checking practices and which do not.

Data Analysis and Reporting. Consistent guidelines and protocols for analyzing and summarizing data are needed before actual data collection begins. Project personnel may want to compile a periodic report of the summary statistics for the monitoring data, and some suggestions for a more detailed analysis to be conducted later. A more detailed plan for the data analysis of the inventory or short-term studies is presented with sufficient detail so that reviewers can evaluate not only the merit of the statistical procedures but also whether the data collected are appropriate for the proposed analysis (Liggett 1985). The plan also provides for periodic evaluation of the precision and accuracy of the data from the QA measurements.

The completeness of the data record is evaluated as well, including data-quality goals as levels beyond which corrective action should be taken. QA parameters are tracked to identify significant changes in data quality or differences between observers, even if specific QA targets cannot be set.

Study Documentation

Careful documentation continues throughout each I&M project, including the following:

- on-the-ground site descriptions and observations
- explanations of any deviations from sampling methods in the study design
- sampling dates and personnel associated with all data collected
- periodic precision and accuracy checks of all methods and personnel
- redundancy and security of all data promptly after data collection

Site Descriptions. Site descriptions are included as part of most field studies; the site locations are documented so that the sites may be relocated in the future. Individual study sites are permanently marked in the field and on topographic maps or aerial photographs, and the sites are discussed in sufficient detail to allow someone not on the original sampling crew to relocate them. Global positioning systems determine accurate locations for the monitoring work in which sampling is repeated at the same location. One method of permanently marking plots is described in Zedaker and Nicholas (1990).

Exceptions to this rule include studies involving many sites and relatively few samples at each site. The extra time that is required to document site locations reduces sample size too much, and onetime sample locations are more appropriate. Mapping projects, short-term research projects, and broad-scale inventory projects fall into this category. Trail condition monitoring also tends to involve quick measurements at many sites, with no effort to sample the same locations year after year (Hammitt and Cole 1987).

Deviations from Protocols and Changes in Methods. The methods that are described in the methods manual are consistently followed throughout the course of the study. However, unusual situations or mistakes in the course of sampling lead to occasional deviations from the prescribed methods. These changes are recorded as soon as possible after they occur. All data sheets include comment spaces. Changes in the methods sometimes are made during the course of a study, and each change is recorded in detail. What method used to collect each portion of the data is carefully noted. The methods manual is updated with the new methods. Personnel do not stop documenting the old methods, which are clearly marked as outdated or moved to an appendix so no confusion occurs about what method is current. Personnel calibrate the methods with one another to determine the possible effect of a change on the actual measurements.

Sampling Dates and Personnel. All data sheets have spaces for the date of sampling and the people who did the sampling. Asking the people involved with the sampling to clarify ambiguities or discrepancies on the data sheets is then possible.

Precision and Accuracy Check Data. Data from all precision and accuracy checks are maintained as an integral part of the database, and the data are periodically analyzed and examined over the course of the study. Although one of the functions of collecting these data is simply to have a description of the precision and accuracy of measurements to provide quality assurance for a completed study, conducting an ongoing check is also useful. The frequency with which QA data are examined depends on how much data loss is tolerated if a problem is found (Lockhart 1985).

Data Storage. Data sheets and computer files are duplicated often, and copies are stored in separate buildings. Records on the status of the data processing are maintained. Personnel involved with a project at any point in time are able to figure out which data have been entered, which have been validated, and any other processing that has been conducted. Data management is addressed in greater detail in the following section.

Data Management

Sound data management procedures are the key to successful quality assurance and a credible I&M program. The objectives of data management are to ensure that data are (1) stored and transferred accurately and (2) secured from loss or damage. In addition, data structures and format are documented in sufficient detail so that someone not involved in the original project can interpret their meaning and evaluate their precision and accuracy. Data management includes:

1. Data verification: double entry from original data sheets, or cross-checking of final entered data back to original data sheets or electronic data format
2. Data validation: checking data for reasonableness against a variety of standards, such as acceptable ranges, lists of appropriate species codes, etc.
3. Summary and analysis of precision and accuracy check data for all variables
4. Documentation of variable names, measurement units, missing value codes, and meaning of coded data
5. Documentation of personnel and dates of collection, entry, verification, and validation of data
6. Documentation of validation procedures and any manipulations or analysis of the data, including computer programs or commercial software used
7. Data storage *with associated documentation* in multiple copies and multiple locations, and careful curatorship to ensure that all copies are updated whenever new material is added or changes are made

Data Verification

All data entered into a computer from data sheets or electronic data formats are verified by entering data (1) twice (preferably by different people) and comparing the resulting computer files or (2) once and visually comparing *every* number with the entries of the original data sheets (Zedaker and Nicholas 1990). Optical character readers eliminate most mistakes, assuming data sheets are relatively clean and legible. Verification procedures vary for data that are gathered electronically, either with hand-operated field dataloggers or from electronic instruments interfaced with a datalogger. Part of the calibration and precision and accuracy check procedures include ensuring that the data are accurately logged. Data verification ensures that the data are accurately transferred from datalogger to computer. The best way to verify accuracy of this data transfer is to simply transfer the data twice and compare the results (Zedaker and Nicholas 1990). Most data transfer software provides error-checking, but additional verification is not difficult in most cases.

Data Validation

Data are validated by checking them for reasonableness. A variety of checks are performed, depending on the type of data (Cadle 1985). The most basic procedure is simply to scan the data for reasonable values. For example, species code, crown class, precipitation type, and many other variables have a finite number of valid codes. Having the computer check to ensure that no invalid codes have been entered is relatively simple. Continuous variables, such as dbh, soil temperature, and ozone concentration, do not have a limited number of valid codes but do have an expected range of values; the computer checks whether values are within a range that is considered reasonable. These kinds of checks are easily incorporated into the data entry programs on the computers or field dataloggers, so errors are identified quickly.

A more complex level of validation is checking for internal consistency between variables. For example, a dbh measurement of 150 cm is reasonable in itself, but is illogical when combined with a species code for vine maple *(Acer circinatum),* which is normally a small tree. Similarly, an ozone value of 100 ppb is reasonable in itself, but is questionable when it occurs on a cold, rainy November morning.

Finally, data are compared with other observations in the data set. For example, an ozone value of 110 ppb is reasonable, but merits closer examination when it occurs as a spike in a continuous series of 50 ppb measurements. A computer identifies outliers relative to nearby measurements or the entire data set; these outliers are then examined more closely.

Analysis of Quality Assurance Data

The precision and accuracy data are summarized for each parameter in the study and for subgroups, such as treatments, individual personnel, or sampling periods. A completeness value to show the percentage of all possible data that were actually collected is computed (Mitchell et al. 1985). Completeness is nearly 100 % in some cases. However, instrument calibration time and preventive maintenance may result in data recovery substantially less than 100%, even when no problems exist. This information is included with the actual data set so that it is available to anyone using the data.

Documentation of Data Sets

All data sets are produced in both paper form and on the electronic media on which data are stored. Documentation includes (1) the names of all variables, (2) which measurement each variable represents, (3) methods used for measurements and a reference to a more detailed method description, (4) units in which data are expressed, (5) the meaning and codes used for any coded data, (6) QA results for all variables for which data were collected, (7) interpretation of any outliers or suspect data, and (8) codes used for missing values.

Metadata

Accurate metadata are the key to data storage, transfer, and appropriate use. They allow users of a data set to interpret data contents, structure, and formats for various applications. A number of draft Federal Geographic Data Center (FGDC) metadata elements have been documented by the National Park Service (U.S. Department of the Interior, National Park Service 1993), which specifies information on data set identification, geographic projection, data custody, access, completion and availability status, source, table definitions and attributes, processing steps, data quality, and metadata references. Spatial data are also documented in conformance with FGDC appropriate spatial data transfer standards. Documentation of all the data sets is produced both in paper form and on the electronic media on which data are stored. Metadata include any explanatory comments that are necessary to understand and use the data set. The most current information on metadata standards should be consulted (e.g., NPS/GIS sourcebook, regional GIS coordinator, or FGDC publications).

Documentation of Data Management Actions

Data management activities are documented as they are performed and a record kept of when and by whom all data are entered, verified, and validated. All other processing actions are also recorded.

Documentation of Validation and Analysis Procedures

The procedures that are used for data validation, manipulation, and analysis are thoroughly described, and the criteria for the decisions on invalidation of any of the data are explained. Computer programs are retained for validation, manipulation, and analysis, and their QA role is explained.

Data Storage

Final data sets are archived with all the supporting documentation, including data file documentation, data management procedures, and QA data. Multiple copies of data sets are stored and all copies updated when additional material is added to one copy. Data are copied to new magnetic media periodically to maintain the integrity of the data and to ensure compatibility with new computer technology.

Implementing Quality Assurance and Data Management

The previous discussion offers guidelines for developing QA and data management procedures as part of an I&M program. Although these aspects of inventory and monitoring may seem like a burden, they ensure that a park has a technically sound, credible, and defensible program. If these guidelines are instituted at the beginning of each I&M project, they become a routine part of project operations. Each park may not have the expertise to develop QA and data management procedures on its own. Therefore, identifying cooperators who have more background in this area is important. Possible cooperators include personnel from other parks, from NPS regional offices or various divisions, from other agencies, and from universities. Outreach opens doors to cooperators who are interested in participating in I&M projects and adds elements that the park itself cannot fund.

No single reference or manual contains all the information that is needed to develop QA and data management guidelines for national parks. The I&M coordinator for each park determines how and where to obtain this information and what level of detail is needed for each I&M project. In addition, I&M project managers balance the completeness of quality assurance and data management against available funding and labor. Budget and personnel requirements for quality assurance and data management should be included in the original estimates for each I&M project to avoid unexpected costs later in the program.

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Appendix A: I&M Projects by Resource Category and Level of Effort

Resource Category	Level of Effort: Compile Existing Information	Level of Effort: Conduct Resource Inventories	Level of Effort: Establish Monitoring
Atmospheric			
Precipitation			
Temperature			
Relative humidity			
Wind			
Incident radiation			
Microclimate			
Air quality			
Visibility			
Criteria pollutants			
Ozone			
Sulfur dioxide			
Nitrogen oxides			
Carbon monoxide			
Particulates			
Deposition			
Wet			
Dry			
Geologic			
Event records (e.g., landslides)			
Geologic map			
Minerals			
Rock types			
Landforms			
Soils			
Classification			
Erosion			
Physical characteristics			
Chemical characteristics			
Sediment movement			
Streams and rivers			
Lakes and reservoirs			
Ocean shore			
Geothermal activity			

Resource Category	Level of Effort		
	Compile Existing Information	Conduct Resource Inventories	Establish Monitoring
Hydrologic			
Groundwater			
Quantity and distribution			
Chemical characteristics			
Streams and rivers			
Physical characteristics			
Chemical characteristics			
Discharge quantity and timing			
Lakes and reservoirs			
Physical characteristics			
Chemical characteristics			
Ocean			
Physical characteristics			
Chemical characteristics			
Snowpack			
Quantity and distribution			
Chemical characteristics			
Duration of snow cover			
Glacial activity			
Geothermal activity			
Flora			
Nonvascular			
Bryophytes			
Distribution and abundance			
Growth and productivity			
Physiological status			
Pathogenic agents			
Air pollution			
Algae			
Distribution and abundance			
Growth and productivity			
Fungi			
Distribution and abundance			
Growth and productivity			
Animal interactions			
Herbivory			
Human use and control			

Resource Category	Level of Effort		
	Compile Existing Information	Conduct Resource Inventories	Establish Monitoring
Lichens Distribution and abundance Growth and productivity Physiological status Pathogenic agents Air pollution Vascular Distribution and abundance Growth and productivity Physiological status Pathogenic agents Air pollution Insects Fungi, bacteria, etc. Animal interactions Herbivory Human use and control			
Fauna Prokaryotes/protists Invertebrates Terrestrial Insects Distribution and abundance Human control Other Distribution and abundance Aquatic Insects Distribution and abundance Brachiopods, molluscs, crustaceans Distribution and abundance Human use Other Distribution and abundance Vertebrates Terrestrial Amphibians Distribution and abundance			

Resource Category	Level of Effort		
	Compile Existing Information	Conduct Resource Inventories	Establish Monitoring
Reptiles Distribution and abundance Birds Distribution and abundance Human interactions and harvest Mammals Distribution and abundance Human interactions and harvest Aquatic Amphibians Distribution and abundance Birds Distribution and abundance Human interactions and harvest Fish Distribution and abundance Human interactions and harvest Mammals Distribution and abundance Human interactions and harvest			
Ecosystem and Landscape Structure and Function Terrestrial systems Biomass and productivity Energy flow Mineral cycling Climatic effects Fire effects Human impacts Aquatic systems Biomass and productivity Energy flow Mineral cycling Human impacts Landscape patterns Role of park in region Isolation of park Spatial patterns			

	Level of Effort		
Resource Category	Compile Existing Information	Conduct Resource Inventories	Establish Monitoring
Nonrecreational Human Activity			
Livestock grazing			
Permit activity			
Illegal grazing			
Range condition			
Range restoration activity			
Mining			
Permit activity			
Illegal mining			
Water movement from site			
Surface flow			
Quantity			
Chemical characteristics			
Biological characteristics			
Subsurface flow			
Quantity			
Chemical characteristics			
Mine reclamation activity			
Wood gathering			
Permit activity			
Illegal wood gathering			
Available wood resource			
Quantity			
Condition			
Subsistence use			
Permit activity			
Harvest levels			
Animals			
Plants			
Off-road vehicle activity			
Gathering and consumption (berries, fungi)			
Permit activity			
Illegal activity			
Collection of natural or cultural artifacts			
Permit activity			
Illegal activity			
Air traffic			
Permit activity			
Quantity			
Noise level			
Illegal traffic			
Transportation			
Automobile traffic			
Commercial traffic			
Trucks			
Air transport			
Watercraft			

Resource Category	Level of Effort		
	Compile Existing Information	Conduct Resource Inventories	Establish Monitoring
Pollution impacts Air quality Noise Management Activity Structures and developed areas Activity by resource management personnel Science-related activities Restoration activities Maintenance activities Historic human use			
Recreational Human Activity Sport hunting and fishing Hunting Permit activity Harvest level Illegal hunting Wildlife population levels Fishing Permit activity Harvest level Illegal hunting Wildlife population levels Backcountry use Permit activity Hiking Rock climbing and mountaineering Camping Gathering and consumption (berries, fungi) Vehicle use (mountain bikes, snowmobiles, off-road vehicles, etc.) Watercraft use (boats, canoes, rafts) Noncompliance levels Impacts Terrestrial resources Aquatic resources Restoration activities Developed area use Hiking Rock climbing Camping Gathering and consumption (berries, fungi)			

Resource Category	Level of Effort		
	Compile Existing Information	Conduct Resource Inventories	Establish Monitoring
Vehicle use (mountain bikes, snowmobiles, off-road vehicles, etc.) Watercraft use (boats, canoes, rafts) Lodging and dining facilities Noncompliance levels Illegal activities Impacts Terrestrial resources Aquatic resources Restoration activities			

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As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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